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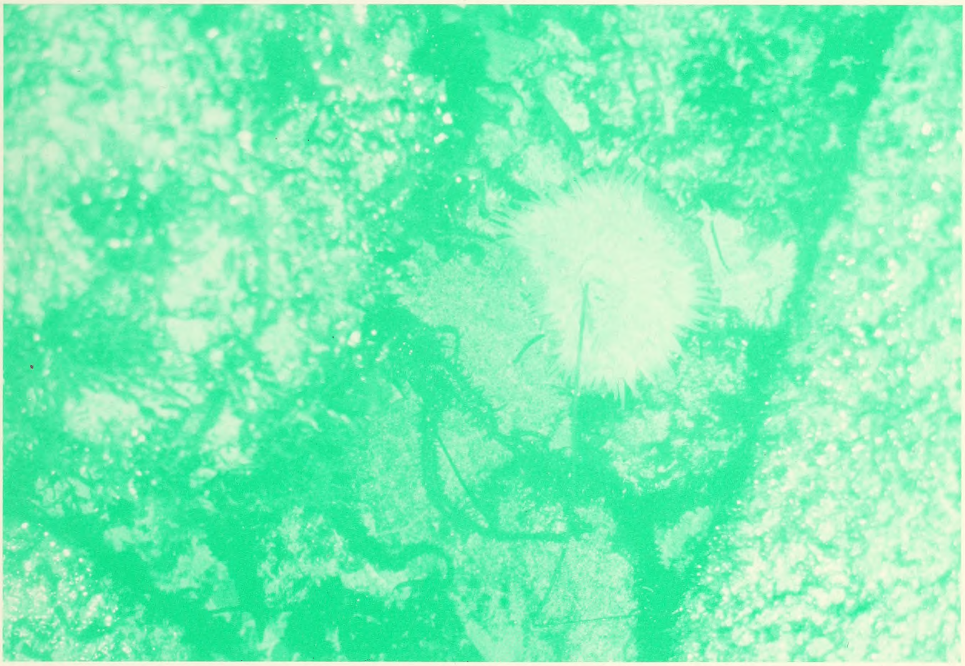

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Proceedings of a Special Symposium: Coastal Watersheds and their Effects on the Ocean Environment Sponsored by The Southern California Academy of Sciences May 5, 1995

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Preface

In the past century, the Southern California coastal zone, like many coastal zones in this country, has been changing from rural and agricultural uses to urban and industrial, dramatically altering the nature of our watersheds and adjacent coastal shelves. This process has altered hydrologic patterns and associated movement of sediments, and has contributed to increased loads of pollutants washing from watersheds to offshore marine environments. In addition, natural events such as fires and floods, especially those we endured during 1995, have their own unique effects.

Watershed management has become a topic of major public concern. Over the past several decades, we have seen significant progress in cleaning up point sources of pollution from sewage treatment and industrial plants. But a large problem remains with nonpoint sources of contaminants entering coastal systems from our urban storm drain systems and polluted waterways. Our goals as scientists should be to first identify and quantify the many problems associated with urban runoff, and to work with resource managers to develop, prioritize, and implement cost-effective solutions. This approach is the essence of the National Research Council's (NRC) framework for managing coastal resources contained in the report "Managing Wastewater in Coastal Urban Environments" (1993). Integrated Coastal Management (ICM) strategies are based on consideration of regional differences, multiple sources of perturbations, costs, and benefits. The NRC framework (1993: p. 14) stressed that implementation of ICM, among other things, needs to be based on the best scientific knowledge available about ecological functions, and that a trans-disciplinary perspective is critical in coastal problem solving.

A one-day symposium was held at the 1995 Annual Meeting of the Southern California Academy of Sciences entitled "Coastal Watersheds and their Effects on the Ocean Environment." The purpose of this symposium was to highlight the importance of the overall issue, to bring together local research from a variety of disciplines, and to identify gaps in our knowledge base. The morning session was concerned with water quality and pollutant loading, the effects of pollutants on marine life, improvements in monitoring technology, and changes in sediment delivery and erosion in the coastal zone. The afternoon session tackled coastal erosion and management, nutrient loading in estuaries and wetlands, and pollution sources in the urban watershed. We also included two student poster presentations, one on fecal indicators in L.A. coastal waters, and a second on transportation sources of pollution in the L.A. region. Full papers from five of these presentations are published herein. Others, which are in-press elsewhere, are published here in abstract form.

The breadth of subject matter covered in this symposium publication demonstrates the multifaceted nature of urban watersheds and complexity of the coastal management issues. In our first paper, Sibley examines an international problem of untreated sewage from Tijuana, Mexico flowing past the border to San Diego beaches. Schiff and Stevenson report on a newly instituted watershed-based approach to regional storm water monitoring in San Diego County, a study which attempts to characterize pollutant loading and potential toxicity in a major metropolitan region. Dalkey and Shisko give us a detailed picture of waste water field movement in Santa Monica Bay by measuring salinity anomalies derived from oceanographic measurements from electronic sensors. Bay et al. characterize levels of toxicity of dry weather flow using sensitive life stages of three marine organisms. They further attempt to identify the toxic components which were responsible for the observed toxicity. We proceed to a field study by Martin et al. showing the detrimental effects of freshwater inundation from street runoff on a species of intertidal sea anemone. In the final paper, Duke et al. looks at the transportation industry as a source of pollutants.

We wish to acknowledge the Southern California Academy of Sciences for sponsoring the original symposium as part of its annual meeting. A special thank-you to the authors for contributing papers to this symposium issue, to the reviewers for contributing their expertise in editing the papers, and finally to Southern California Sea Grant Program at the University of Southern California for providing financial support for this symposium issue of the Bulletin.

Susan E. Yoder, Ph.D.
John H. Dorsey, Ph.D.
February 1996

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The Border: Sharing a Problem and a Solution

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Abstract.—The Tijuana River flows through two countries. It passes through the poverty-stricken but growing community of Tijuana, Mexico and southern San Diego County where it empties into the Tijuana Estuary. Raw sewage from Tijuana and the surrounding watershed is dumped into the river as it flows to the Pacific Ocean. Littoral currents transport the waste north to beaches in San Diego County, creating health risks and forcing beach closures. Repeated attempts to remedy the situation have been made since 1930, however, successful sewage treatment has not been attained. Lack of money from Mexico and different standards for sewage treatment between the United States and Mexico have made this situation difficult to remedy.

Valuable opportunities are available to California because of its coastal location. However, careful management of marine resources is necessary to keep this asset viable for the future. Mexico and California share a river that has become an international issue because of poor management. The Tijuana River runs through some of the poorest areas of Tijuana, Mexico, picking up raw sewage and transporting it across the border through agricultural areas of southern San Diego County and finally discharging into the Tijuana Estuary on its way to the ocean. Littoral currents carry the waste north to beaches in San Diego County, creating health hazards and beach closures along several miles of coastline (Fig. 1). This is not a new phenomenon to this area, but has been happening since the 1930's.

In 1934 the Tijuana River was a concern to the International Boundary Commission because of sanitary conditions. The San Ysidro area, just north of the border, received run-off from the river and the sale of truck crops from that area was prohibited (Mydans 1990). A survey and study of the area was conducted, and in 1937, six and a half miles of sanitary sewer lines were constructed from near San Ysidro to the Pacific Ocean. The cost to the United States was $150,000, and was paid from emergency funds. The Mexican portion consisted of several miles of main lines and a sanitation plant in Mexico, near the border between the two countries (U.S. Bureau 1941).

Failure of the Sewage System

The population of Tijuana has grown considerably since the 1930's and the sewer system quickly became inadequate to handle the amount of sewage running into the small river. Nearly two million people live in Tijuana today, and less than half the population has plumbing. Recent industrial growth in the city and failure to enforce environmental laws contribute to the pollution of the river. The rapid population growth in Tijuana, especially after World War II, and the subsequent large amount of sewage dumping into the river caused the quarantine of

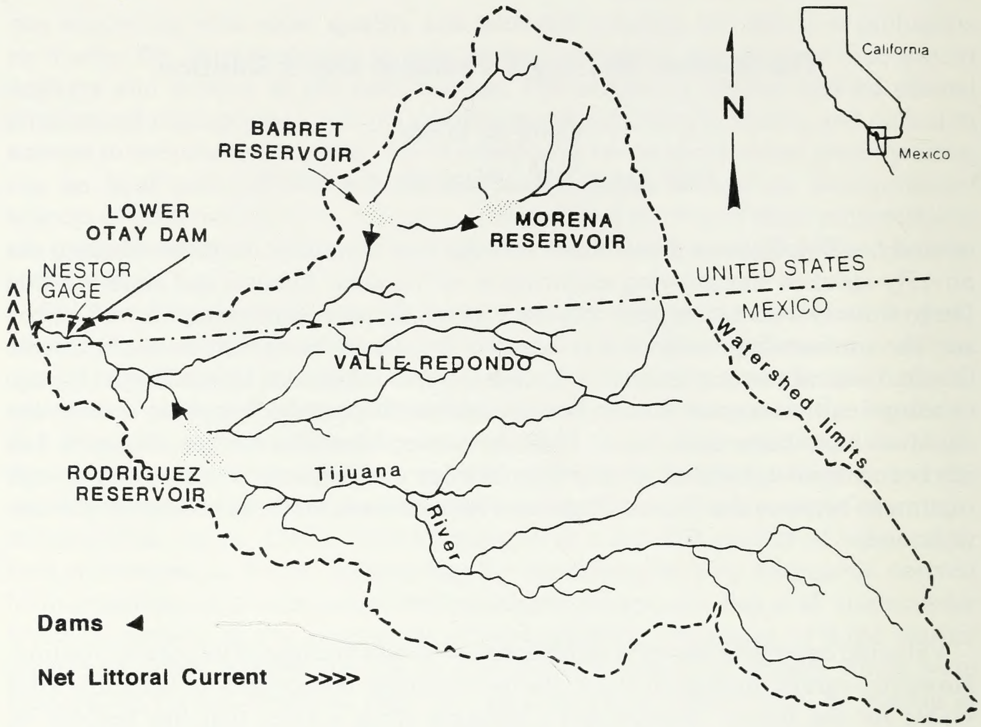

Fig. 1. Tijuana River Watershed.

Imperial Beach in San Diego County in 1959. The beach was re-opened in 1962 after Tijuana built another sewage system, but closed again in 1965 after the system repeatedly failed. To aid the situation, an emergency pipeline was constructed to carry up to 13 million gallons of sewage a day to the Point Loma Sewage Treatment Plant in San Diego. By 1980 this pipeline was at full capacity from population pressures on both sides of the border.

This arrangement is now renewed on a year-to-year basis. Yet, the combination of breaks in the Tijuana sewage plant and incessant dumping of raw sewage continue to pollute the river and the Pacific Ocean where it empties. In response, the International Boundary Water Commission (IBWC) was formed by the Mexican and U.S. governments to monitor the effects of 32 to 38 million gallons of sewage discharged each day (Boesch 1990).

Tijuana River Estuary

The Tijuana River and its tributaries drain a series of marine terraces and cross the border just north of Tijuana where it combines with water from the Pacific Ocean and exits at the Tijuana Estuary. The combination of these waters, the change in topography, and the consequence of tidal flow and streamflow provide a diverse habitat for a variety of birds plants, animals, fish, insects and organisms. The estuary is part of the Pacific Flyway and hosts thousands of waterfowl and shorebirds during winter migration. Several water-associated birds that are rare or endangered are often sighted there (Zedler et al. 1992).

The quality and quantity of water that drains into it is vital for the survival of plant life, fish, birds and other small animals. With three-fourths of the river's watershed in Mexico, it is difficult to control pollutants that flow into the river (Fig. 1). Furthermore, because watersheds from both countries create the estuary, it is internationally significant.

Water Sanitation Monitoring

Both the California Department of Health Services and the San Diego County Department of Health Services perform monitoring programs on the coast. Alarming results of water quality testing between 1977 and 1987 prompted more intensive monitoring (Boesch 1990). The data collected is shared with regional quality boards and other state and federal agencies. Volunteer work reflects San Diego residents' concern about their water quality and has also been effective in reporting physical evidence of sewage in the areas of recreational activity. Beaches have been closed when citizen reports have proven valid.

Waste Discharge to the Ocean

The Water Quality Control plan for ocean waters of California is set by the State of California State Water Resources Control Board. In Chapter III of the 1990 plan, the general requirements for management of waste discharge to the ocean is clearly stated. "Waste management systems that discharge to the ocean must be designed and operated in a manner that will maintain the indigenous marine life and a healthy and diverse marine community."

The Tijuana sewage plant now treats about 25 million gallons of sewage a day, but Mexican standards for sewage treatment are much lower than those in the United States and problems occur when ocean currents carry the discharge north to San Diego Harbor. Effective sewage treatment is expensive and Mexico has not provided the financial resources to properly treat the sewage. County Officials in San Diego can only post signs to alert people that the beaches are contaminated and unsafe for swimming even though the water may look safe (Mydans 1990). The sewage treatment plant in the U.S. is already processing sewage at capacity, but more problems occur with heavy storms, such as one in the winter of 1991. This storm was partially responsible for a break in a pipeline which carried sewage out to sea for dumping. The release of this partially treated sewage and the discharge of the Tijuana River raised bacteria readings from Point Loma and beaches two miles north to more than 400 times the legal limit. Now, after fifty years of requests for help a solution may be at hand.

A U.S. and Mexico environmental pact was signed in October 1989 which emphasizes United States–Mexican border environmental problems. This agreement includes cooperation from both governments in the construction of a San Diego based sewage treatment facility. The estimated cost of the sewage plant is $400 million, and requires both countries to share the financial responsibility as stated in the IBWC report of 1990. Because the water quality standards in the United States are more strict, the construction, operation and maintenance of deep ocean outfalls will be financed by the United States. Mexico agreed to repay the U.S. for any initial costs made on the construction of the sewage plant. However, the agreement also states that each country's financial obligation is subject to availability of funds (IBWC 1990). Combined efforts of the U.S. federal government, California, the IBWC and San Diego have allocated $339.7 million for the sewage plant, but Mexico has not designated any funding for the project yet (Woo 1995).

A projected completion date for the South Bay International Wastewater Treatment Plant is 1996, with the outfall to be completed in 1998/99. An Environmental Impact Statement has not been completed for the outfall yet, and during the interim period between plant completion and a functioning outfall, there is concern about where the treated sewage will go (Woo 1995). Release into the Tijuana River would have adverse effects on the estuary.

Conclusion

Sharing a border with a foreign country can be a delicate matter, especially when they have contrasting economies. A major pollution problem exists in the Tijuana River, where the course of its flow involves both the U.S. and Mexico. The U.S. has nothing to do with the origin of sewage in Mexico, but involvement cannot be avoided when it affects U.S. land and water. The remedy for the Tijuana River problem is costly, yet the alternative of doing nothing because of inequitable financial obligation is even more environmentally costly. Even if the pollution entering the ocean did not flow north to California beaches, the marine environment and the future of many valuable species in the estuary and surrounding coastal waters should be of concern to U.S. citizens. The Tijuana River contamination at the border may pale in comparison with larger global environmental issues, but it is a regional problem that needs to be addressed regardless of citizenship.

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San Diego Regional Storm Water Monitoring Program: Contaminant Inputs to Coastal Wetlands and Bays

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Abstract.—A watershed-based, Regional Monitoring Program was established by the City of San Diego, the County of San Diego, the San Diego Unified Port District, and 17 other incorporated cities within the county to evaluate the water quality of their wet weather runoff. Seventeen different locations were sampled between 1993 and 1995, and samples were analyzed for priority pollutants and toxicity. In general, measurable quantities of some metals and fecal indicator bacteria were found consistently while nearly all organic contaminants were below method detection limits. Results indicated that residential areas had similar event mean concentrations (EMC) of suspended solids, oil and grease, cadmium, chromium, nickel, and zinc compared to industrial or commercial areas. The EMC of copper and lead from residential areas were higher relative to commercial or industrial areas. However, even EMC from residential areas of San Diego were lower than the EMC from other urbanized watersheds measured from around the country as part of the Nationwide Urban Runoff Program. Potential receiving water effects included 7-day chronic toxicity of storm water effluents to *Ceriodaphnia.* Storm water was responsible for increased contamination of Mission Bay receiving waters by fecal indicator bacteria and exceedences in water quality objectives resulted in post-storm beach closures.

Over the past twenty years tremendous effort and resources have been used to measure contaminant inputs and effects of pollutant discharges to the coastal environment of southern California. An estimated $17 million is spent annually on pollution monitoring efforts (NRC 1990). The vast majority of these resources are used for monitoring point sources such as publicly owned sewage treatment plants. Non-point source discharges however, such as runoff from urban surfaces during storm events, has been shown to contribute more discharge volume and similar quantities of total pollutant mass loading as sewage treatment plants (Cross et al. 1990). Additionally, non-point source discharges enter the nearshore marine environment, often through estuaries or bays, wholly untreated. Sewage treatment plants often have the capability of either enhancing removal of pollutants and/or disinfection prior to discharge and effluents are typically released well offshore. Bays and estuaries are active ecological zones (Zedler and Nordby 1986), potential nursery grounds for fishes and invertebrates (Cross and Allen 1993), and have the largest potential for body contact recreation (Kinnetic Laboratories 1994a).

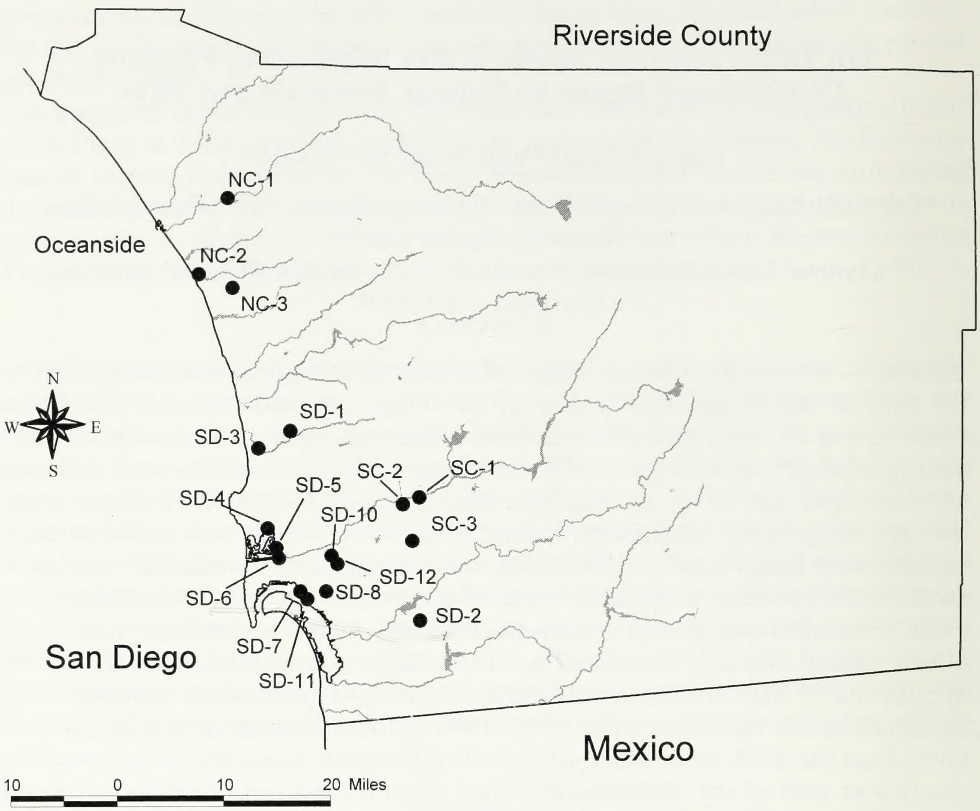

Fig. 1. Map of the major creeks and rivers which drain the urbanized areas of San Diego County. See Table 1 for a key to monitoring stations.

Part of the problem associated with the lack of measuring and/or treating non-point source discharges is the variability of rainfall and the inability to control exactly when and how much runoff is going to occur. Southern California receives between 12 and 14 storms per year. The wettest months of the year are January and February, but significant storms typically arrive from October through April and this time period contributes over 95% of the total annual rainfall (NOAA 1995).

In 1993, the Regional Water Quality Control Board, San Diego Region (RWQCB) instituted a wet weather monitoring program for the general discharge of urban storm waters in San Diego County. The wet weather monitoring program was mandated under the Code of Federal Regulations, Title 40, part 122.26 (d) (2) (iii) and the Clean Water Act, and is detailed in the National Pollutant Discharge Elimination System (NPDES) Permit Number 90-41. Figure 1 shows the 13 major streams and rivers which discharge to coastal marine waters in this region. It was apparent that many of these waterways cross numerous municipal boundaries. Therefore, a watershed-based approach, or "Regional Storm Water Monitoring", was adopted by the 20 jurisdictions which are listed in the NPDES Storm Water Discharge Permit including the City of San Diego, the County of San Diego, the incorporated cities within the County, and the San Diego Unified Port District.

The San Diego Regional Storm Water Monitoring Program was designed to; 1) directly measure pollutant concentrations and mass loading discharged from large urbanized watersheds during storm events, 2) characterize the water quality of runoff from small watersheds of homogeneous land use indicative of residential, commercial, and industrial areas within the region, and 3) investigate receiving water impacts through the use of toxicity tests and water quality objectives. Other objectives of the Regional Storm Water Monitoring Program, but outside the scope of this paper, were also addressed including modeling inputs of pollutants using computer algorithms or measuring sediment-associated pollutants and biological impacts at the mouth of an urbanized creek.

Materials and Methods

All storm water samples were collected using automatic, telemetering, flow-weighted compositing storm water monitoring stations. Automated stations were selected since first storms of the year and first flows during a storm were required for monitoring. A flow-weighted compositing strategy was a favorable approach since pollutant concentrations in storm waters can vary orders of magnitude depending upon flow and individual grab sampling can bias results. High resolution pressure transducers mounted in the bottom of creek beds or storm drain pipes were used to measure runoff stage (depth) at 30-second intervals. Customized software was then used to estimate instantaneous, 15-minute average, and 24-hourly flow characteristics, as well as cumulative runoff volume measurements. Non-contaminating peristaltic pumps fitted with Teflon tubing were used to collect water samples in pre-cleaned, large volume, borosilicate glass carboys. All flow and sampling data were logged by micro-computers installed in each monitoring station and relayed to storm personnel via modem communications. Field crews visited each station before, after, and periodically during each storm to calibrate equipment, verify operating status, and collect samples not amenable to a flow-compositing strategy (such as bacterial analysis which requires sterilized containers and very short holding times).

Two general types of watersheds were monitored for the San Diego Regional Storm Water Monitoring Program; 1) "mass loading" watersheds representing large areas (2500 to 108,000 acres) of mixed land uses typically located immediately prior to a receiving water body such as a wetland or bay, and 2) "land use" watersheds consisting of much smaller areas (32 to 422 acres) of a single homogeneous land use indicative of residential, commercial, or industrial land uses within the study area. Table 1 lists the sample sites, type of station, size, and land use. Altogether, 17 monitoring stations were installed and sampled between Fall 1993 and Spring 1995 (Fig. 1).

Each storm water sample was analyzed for 129 priority pollutants using established protocols (USEPA 1983a; APHA 1992; USEPA 1989) including suspended and dissolved solids (EPA Methods 160.1 and 130.2), oil and grease (EPA Method 413.2), volatile organic compounds (EPA Method 624), semi-volatile organic compounds (EPA Method 625), chlorinated pesticides (EPA Method 608), inorganic metals (EPA Method 200), nutrients (Standard Methods 4500, EPA Method 300), and fecal indicator bacteria (Standard Methods 9221 and 9230). Additionally, a subset of samples were subjected to 7-day survival and reproduction toxicity testing with the cladoceran *Ceriodaphnia* (EPA Method 1002.0).

Table 1. Watersheds sampled for the San Diego Regional Storm Water Monitoring Program.

Station code	Station name	Watershed type	Size (acres)	Percent land use: Residential	Commercial	Industrial	Open	Number of storms sampled
SD-3	Carroll Creek	Mass Loading	11,500	20	13	22	45	2
SD-4	Rose Creek	Mass Loading	23,000	16	15	8	60	3
SD-5	Tecolote Creek	Mass Loading	5,900	51	15	1	33	4
SD-6	San Diego River	Mass Loading	108,400	30	8	4	57	3
SD-7	Switzer Creek	Mass Loading	2,560	45	22	2	31	6
SD-8	Chollas Creek	Mass Loading	16,900	63	15	2	20	7
SC-1	Jeremy	Land Use Residential	169	90			10	5
NC-2	Park	Land Use Residential	422	83	14		3	5
SD-12	Landis	Land Use Residential	57	84	16			2
SC-3	Wal-Mart	Land Use Commercial	32		100			5
NC-1	Yuma	Land Use Commercial	32	6	94			6
SD-10	Bramson	Land Use Commercial	41	51	49			4
SC-2	Vernon	Land Use Industrial	56		18	82		5
NC-3	Yarrow	Land Use Industrial	308	1	20	66	13	7
SD-11	Crosby	Land Use Industrial	118	48	10	42		4
SD-1	Top Gun	Construction	31		100[a]			2
SD-2	Proctor Valley	Construction	40	100[a]				2

[a] Area under various phases of active construction.

Most pollutant concentrations in storm water runoff were expressed as the event mean concentration (EMC), a method determined to be of the most value by the USEPA (1983b). The EMC represents the total mass of pollutant divided by the total runoff volume for a given storm event which was measured directly using the automated, flow-weighted composite sampling stations. Since EMCs were distributed log-normally, geometric means are used for summarizing data.

Fecal indicator bacteria have been measured at 20 different stations around Mission Bay on a weekly basis since 1987 by the City of San Diego. Geometric means were summarized to describe temporal and spatial trends from runoff events. Fecal coliform results were stratified into wet and dry days. Wet days were defined as the day of recorded rainfall or the day after a recorded rainfall. Rainfall data from Lindbergh Field was supplied by the National Weather Service.

Results

A total of 14 storms were monitored from fall of 1993 through spring of 1995 which yielded 68 urban runoff samples for analysis of priority pollutants and 10 samples for toxicity. Cumulative rainfall during the 1993–94 wet weather season was near normal (9.86 inches) while the 1994–95 wet season was 60% greater than the long-term annual average (16.03 inches). Mean rainfall of monitored storm events ranged from 0.64 inches in 1993–94 to 0.77 inches in 1994–95. Mean storm duration during both years was approximately 15 hours.

Figure 2 depicts the mass emissions of selected constituents from six different watersheds for median-sized storm events during the 1993–94 water year. The

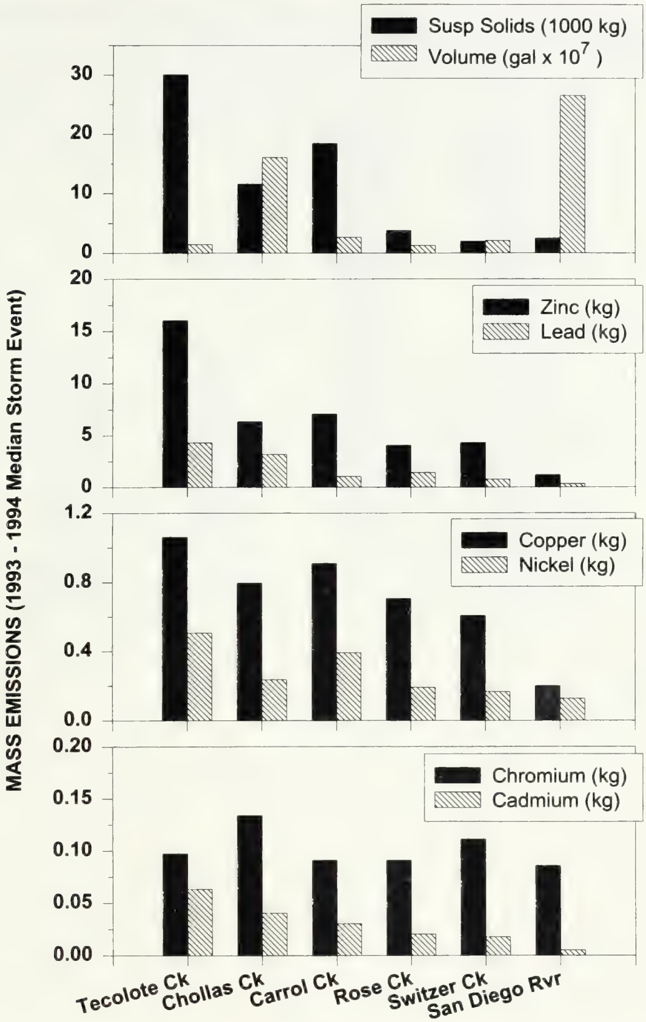

Fig. 2. Mass emissions of selected constituents discharged from six major San Diego drainages during median-sized storm events in the 1993–94 wet season.

San Diego River represented the channel with the largest runoff volume per event and also recorded highest peak flows. The San Diego River however, represented the channel with lowest mass emissions. In contrast, the other large watersheds recorded less runoff volume, but greater mass emissions of suspended solids and six different metals. Concentrations of pesticides, volatile, and semi-volatile organics were nearly always below the method detection limits and consequently, are not shown in Figure 2. Tecolote Creek recorded the greatest pollutant mass emissions of any watershed and drains to Mission Bay, a heavily used aquatic park. Chollas Creek discharged the second greatest measured mass emissions and drains to San Diego Bay, an impaired water body listed by the State of California. Carroll Creek had the third greatest reported mass emissions and drains to Pe-

Table 2. Geometric mean of event mean concentrations (EMC) by land use measured from the San Diego Regional Storm Water Monitoring Program 1993–95.

Constituent	Units	San Diego EMC			NURP Range[a]
		Residential	Commercial	Industrial	
Sample Size		12	15	16	121
Suspended Solids	mg/l	112	89	128	141–224
Oil and Grease	mg/l	1.5	1.9	1.4	
Cadmium	μg/l	0.9	0.6	0.6	
Chromium	μg/l	4.6	2.9	4.4	
Copper	μg/l	25	12	18	38–48
Lead	μg/l	27	11	14	164–204[b]
Nickel	μg/l	6.0	8.3	5.5	
Zinc	μg/l	163	166	162	179–226

[a] Nationwide Urban Runoff Program (USEPA 1983); Range of mixed land uses.
[b] Contemporary lead values range from 6–54 μg/l (LWA 1990).

nasquitos Lagoon, a protected estuary and State Park. The Tijuana River, which receives raw, untreated sewage from regions within Mexico, was not sampled.

Table 2 represents the geometric mean EMC of suspended solids, oil and grease, and six metals for various land uses within urbanized San Diego County. Residential land uses equaled or exceeded the geometric mean EMC for these constituents at other land uses. Residential land use represents the vast majority of urbanized areas within San Diego County (Table 1) and likewise represents a large proportion of the mass emissions to the coastal environment (Kinnetic Laboratories 1994b, 1995). However, concentrations of suspended solids, copper, lead, and zinc in storm water from San Diego representative land use sites were lower than those reported by the Nationwide Urban Runoff Program (NURP) (Table 2). The NURP study measured 121 samples from 28 cities (not San Diego) across the country between 1981 and 1983 (USEPA 1983b). For lead, reductions in the use of leaded gasoline has been reflected in reduced concentrations in storm water (Cross et al. 1990). More contemporary values reported by others (Larry Walker Associates 1990) indicate lead in storm water to range from 5 to 64 μg/l. Differences in the EMC observed between San Diego and NURP results for constituents other than lead may reflect increased source control, better management practices, or reduced flows overall.

Chronic toxicity of runoff samples to *Ceriodaphnia* was observed during five separate storms captured at two different channels between November, 1994 and April, 1995 (Fig. 3). Chronic toxicity which ranged from 12.5 to 50% storm water was measured as the ability to produce offspring and was reported as the No Observed Effect Concentration (NOEC). From the three storms that were sampled simultaneously, Chollas Creek samples were more toxic than Tecolote Creek samples. A seasonal pattern in toxicity was evident from both channels. Early season storms (i.e. before January) exhibited greater toxicity compared to storms later in the season.

Runoff from Tecolote and Rose Creeks affected the temporal and spatial distribution of fecal indicator bacteria in Mission Bay (Fig. 4). There was a strong seasonal cycle in the density of enterococcus in Mission Bay that peaks in the

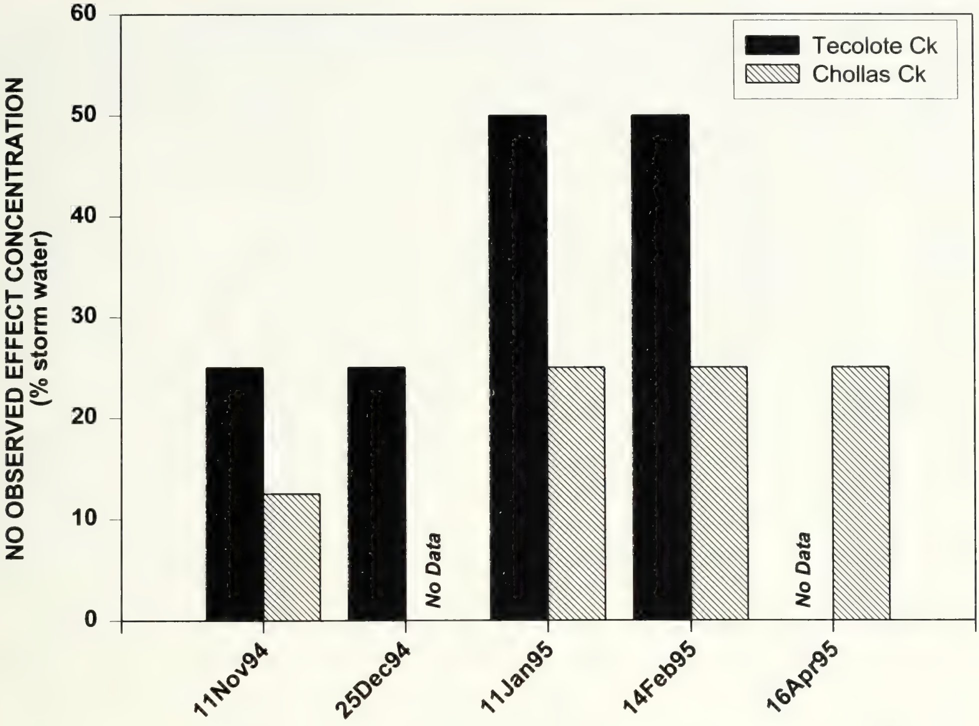

Fig. 3. Chronic toxicity of San Diego urban runoff samples to *Ceriodaphnia dubia* measured during the 1994–95 wet season.

winter when rainfall is greatest (Fig. 4A). In fact, there was a significant correlation of enterococcus density and rainfall quantity (Kinnetic Laboratories 1994a). Furthermore, enterococcus densities in east Mission Bay were higher than densities in west Mission Bay during the wet season, but were similar during the dry season. Figure 4B shows that wet days were always higher for fecal coliform than dry days throughout Mission Bay. Fecal coliform densities during wet days were highest at Station 3 and slowly decreased towards Station 10. Station 3 is located at the mouth of Tecolote Creek. Station 8 is located at the mouth of Rose Creek. In contrast, fecal coliform densities were variable during dry days with no consistent spatial trend.

Discussion

Contaminant concentrations in storm water and pollutant mass emissions discharged during storm events were greatest at Chollas and Tecolote Creeks. Relative to four other large urbanized watersheds in the study area, the loading of suspended solids and most metals during median-sized events were highest at these two channels. Although exact sources of contaminants within these watersheds are unclear, both have a low percentage of open lands relative to the other channels, amongst the highest proportions of residential and commercial land uses, and generate large flow rates which can mobilize pollutants. Tecolote and Chollas Creeks are currently the focus for continued wet weather monitoring.

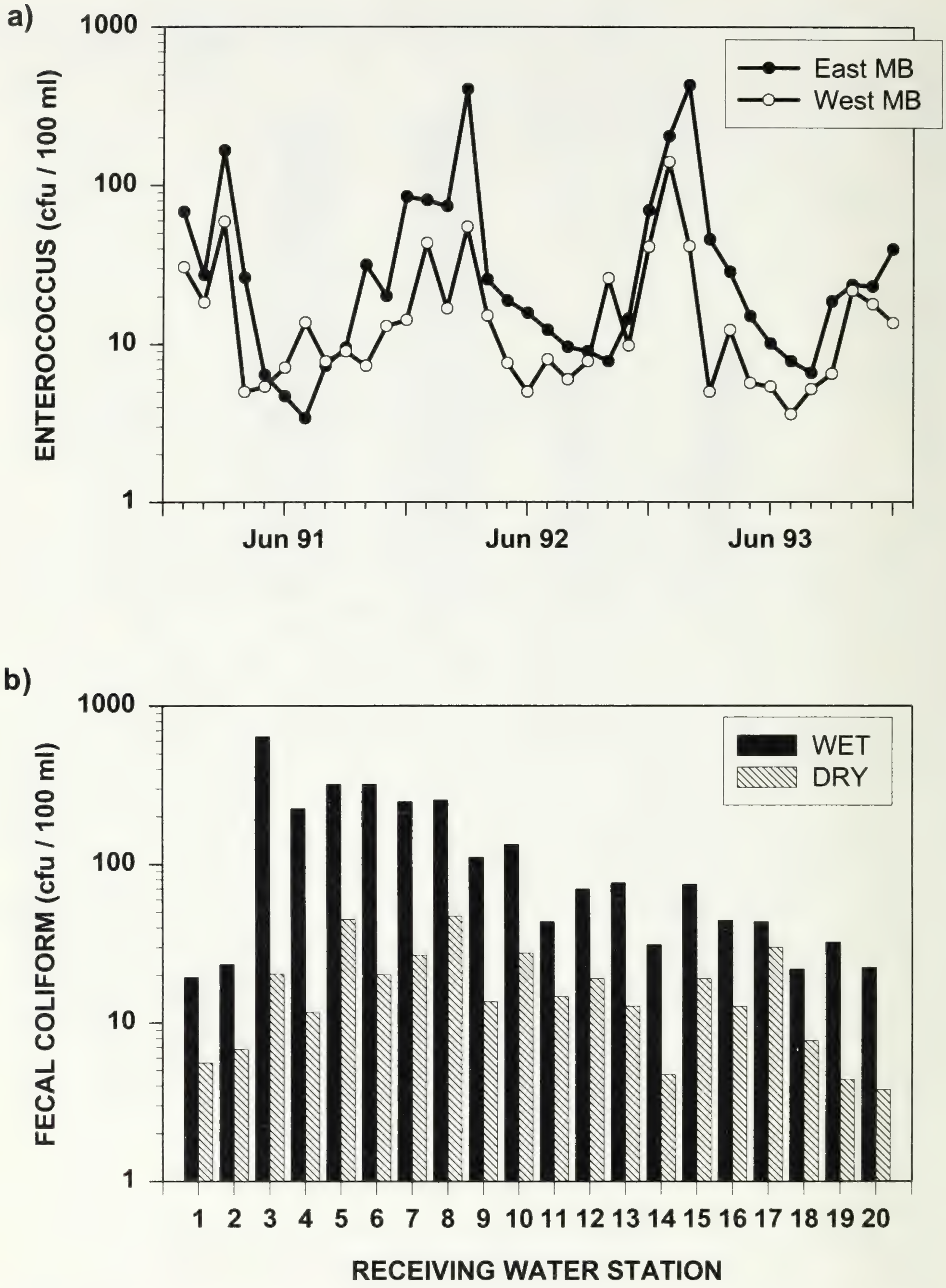

Fig. 4. Temporal (4a) and spatial (4b) distribution of the fecal indicator bacteria enterococcus and fecal coliform in Mission Bay.

Monitoring small watersheds of homogeneous land use revealed that residential areas in San Diego generated pollutant EMCs as high, or higher than, commercial or industrial areas within the county. Residential areas comprised the majority of urbanized land use within the study area. However, pollutant EMCs measured in storm water from residential areas were as low, or lower than, pollutant EMCs measured in storm water from mixed land uses measured from other cities around the Nation.

Although EMCs from urbanized areas within San Diego were lower than other areas nationwide, receiving water effects were observed. Significantly reduced reproduction was measured using *Ceriodaphnia* at concentrations greater than 12.5 to 25% storm water from Tecolote and Chollas Creeks. Other toxicity studies which have exposed aquatic organisms to San Diego storm water have measured impaired larval growth of the fish, *Pimephales* (Kinnetic Laboratories 1995), and significantly reduced hatching success and normal development of *Menidia* and *Medaka* fish embryos (Skinner et al. 1994). Although toxicity has been well documented, the mechanisms and source of toxicity in San Diego storm runoff are still unknown.

Storm water was responsible for increased contamination of Mission Bay receiving waters by fecal indicator bacteria such as total coliform, fecal coliform, and enterococcus. The increased contamination exceeded water quality objectives for these fecal indicators and resulted in beach closures for 99 days during 1993. Fecal indicator bacteria densities were significantly correlated with rainfall quantities and the highest densities were observed near runoff dominated creeks. Other studies measured fecal indicator bacteria in storm drain effluents which were consistently orders of magnitude greater than regulatory limits (Kinnetic Laboratories 1994a). The exact source of the bacterial contamination is still unknown.

A watershed-based approach was used to design a wet weather regional monitoring program in the San Diego area. This approach was successful due to three factors; 1) ability to integrate a study which could answer multiple hypotheses such as estimate total mass loading, generate data for computer based urban runoff models, and evaluate receiving water effects, 2) consistency in methodology of sampling, sample analysis, and storm capture which facilitated comparability for making inter- and intra-seasonal comparisons, and 3) reduced expenditure of resources from sponsoring agencies by not having to run multiple, but disjointed programs.

Acknowledgments

The authors are indebted to the many "storm troopers" that put their personal lives on hold for Mother Nature's gift of rain. Data from the Mission Bay Receiving Water Monitoring Program was supplied by the City of San Diego Environmental Monitoring and Technical Services Division. This work was funded by the City of San Diego and Co-permittees.

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Observations of Oceanic Processes and Water Quality following Seven Years of CTD Surveys in Santa Monica Bay, California

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Abstract.—The Environmental Monitoring Division conducted weekly CTD (conductivity-temperature-density) surveys in the Santa Monica Bay from September 1987 through June 1994 as part of a federal and state mandated ocean monitoring program for Los Angeles City's wastewater discharge. The data provide a unique opportunity to track the development and direction of movement of the discharged wastewater. Direction of wastewater field movement was highly variable whereas seasonal development followed general trends. Salinity anomaly, a measure of the deviation from mean salinity, was devised to more effectively detect the wastewater field and provided for estimation of effluent dilution in situ.

In September 1987, the EPA and California State Water Quality Resources Control Board jointly issued a National Pollutant Discharge Elimination System permit to City of Los Angeles for the Hyperion Treatment Plant which discharges approximately 350 MGD (1.3×10^9 l d^{-1}) of treated wastewater into Santa Monica Bay. The permit required that the City conduct an extensive marine monitoring program in the Bay including weekly water quality program of electronic CTD (conductivity-temperature-depth) profiles. The Environmental Monitoring Division conducted the weekly program from September 1987 through June 1994 until it was replaced with a monthly program following promulgation of a new permit in 1994. During nearly seven years of continuous monitoring under the 1987 permit, surveys were conducted under a variety of conditions including severe drought conditions in the late 1980's and an El Niño Southern Oscillation (ENSO) episode in 1991–92. The result of the program is an immensely comprehensive data set that provides the opportunity to investigate the movement of discharged wastewater in Santa Monica Bay on a weekly basis.

Seasonal oceanographic conditions, currents, and topographic features affect the dispersion and transport of wastewater in the ocean. Many theoretical studies addressing the behavior of wastewater in the ocean have been conducted using mathematical modeling and/or tank experiments. For example, through tank experiments Roberts et al. (1989a, 1989b) described the mixing process of the wastewater field as a two-part process in which rapid, turbulent mixing occurs initially in the near field region and is followed by slower mixing from ambient turbulence in the far field. Recent technological advancements that led to the development of continuous profiling instrument packages have enabled researchers to obtain more information on transport of wastewater through in situ research. Notably Wu et al. (1994) conducted intensive surveys using a suite of physical,

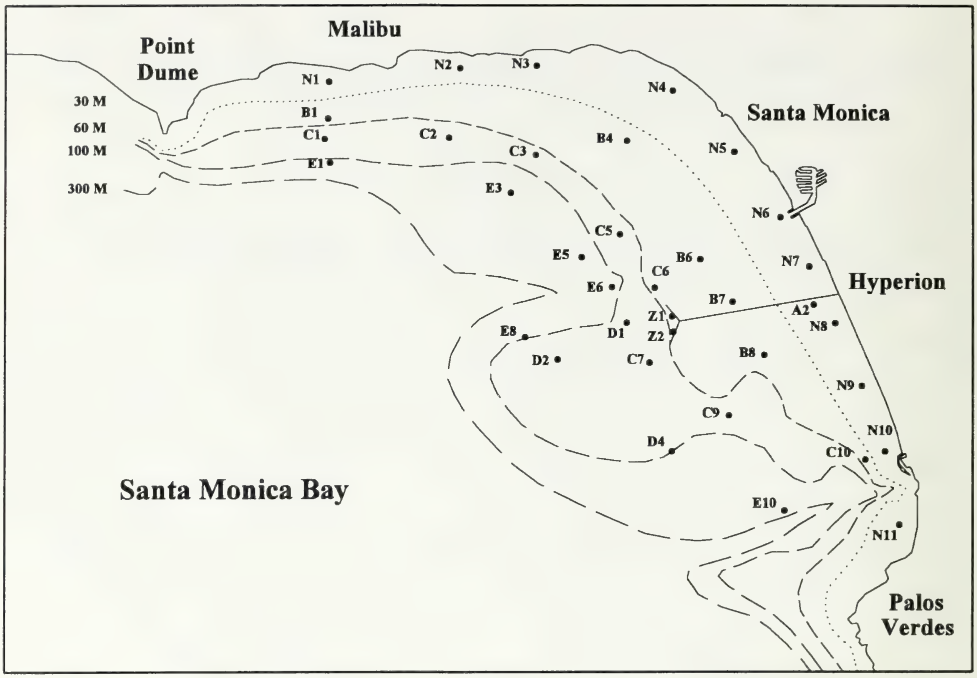


Fig. 1. Water quality stations in Santa Monica Bay.

bio-optical, and nutrient parameters over an eight month period to locate the wastewater field at the White's Point wastewater outfall located just south of Santa Monica Bay. The City of Los Angeles' program is the most comprehensive, resulting in a data set that provides a unique opportunity to thoroughly investigate oceanic processes and transport of wastewater in the ocean.

Materials and Methods

Field sampling.—Weekly CTD profiles were conducted at 36 sites throughout Santa Monica Bay (Fig. 1) beginning 22 September 1987 and continuing through 29 June 1994. Due to the large number of stations and distances between them, sampling was conducted over a two-day period. All nearshore stations and the northernmost and southernmost offshore stations were sampled on the first day and the remaining offshore stations were sampled on the second day. Weather observations for cloud cover, wind speed and direction, and occurrence of rain storms were recorded during the sampling program.

Profiles for salinity (psu), temperature (°C), transmissivity (%), density (kg/m^3), and dissolved oxygen (mg/L) were taken from surface to 2 m above the seabed using a Sea-Bird Electronics Inc. Model SBE-9 CTD system. Sensors for transmissivity and DO were calibrated weekly prior to each cruise, whereas temperature, conductivity, and density were calibrated semiannually by the manufacturer. The CTD unit was also equipped with a pH sensor, but we found that pH data provided little information that was useful for detecting the wastewater field and the sensor was subject to frequent electrode failure.

Data analysis.—Upon return from sea, data were inspected for outliers, and those data points differing by more than 10% from the preceding value were deleted. Mean Bay-wide temperature and salinity was calculated from all surface to bottom measurements taken at all 36 stations for each survey. The resulting means were plotted by fiscal year using SigmaPlot for Windows Version 1.02.

All data were plotted with a custom designed interpolative algorithm, developed by John F. Shisko. The resulting color graphics of CTD data were plotted vertically along depth transects. The shades of color used in these graphics illustrate the relative differences in the data between stations on a scale appropriate for each parameter. The graphics were examined for presence and depth of stratification and the presence/absence of any upwelling. Detailed notes were compiled for each parameter based on these observations of graphics from every CTD survey conducted. In addition, weather patterns were examined to determine the strength and direction of prevailing winds, and the presence/absence and duration of storms.

Color graphics were used primarily to detect the location of the wastewater field and presence/absence of density stratification and secondarily for detecting events such as upwelling. However, salinity is subject to temporal fluctuations that caused scaling problems in the plots that reduced our ability to detect the wastewater field. Therefore, the salinity anomaly was devised to eliminate temporal fluctuations. Salinity anomaly is a measurement of the deviation of salinity at a particular station and depth from the mean Bay-wide salinity as calculated using the following formula:

$$S_{A_i} = \left(\frac{S_{\bar{x}} - S_i}{S_{\bar{x}}}\right)100$$

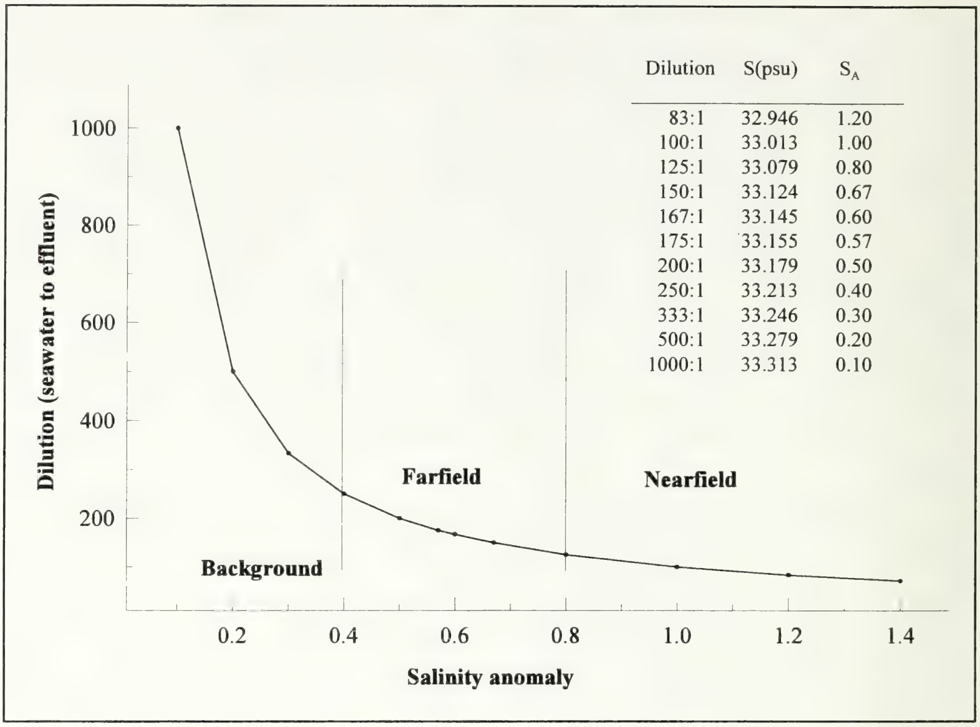
where S_{A_i} is the salinity anomaly at depth i, S_i is the salinity value from site and depth i, and $S_{\bar{x}}$ is the mean Santa Monica Bay salinity as calculated above for the particular survey week.

The relationship between salinity anomaly and wastewater dilution was developed by using theoretical S_A values computed for several wastewater dilutions ranging from 100:1 to 1000:1 (Fig. 2). A salinity value of 33.346 psu was arbitrarily selected as a typical mean Bay-wide salinity for the computations. Effluent salinity was assumed to be zero (effluent normally has an approximate salinity of 0.1 psu). As dilution increases from 100:1 to 1000:1, S_A decreases from 1.0 to 0.10 (Fig. 2).

The wastewater nearfield is defined in this report as water with a salinity anomaly greater than 0.80, with estimated dilutions of 125:1 or less. The wastewater farfield is defined as a lens of water located below the density cap having a salinity anomaly ranging from 0.40 to 0.80, with estimated dilutions ranging from 250:1 to 125:1.

Results

We found that salinity was best for detecting location of the wastewater field of the four directly measured CTD parameters. Our ability to detect the wastewater field was most effective during periods of density stratification but was diminished when stratification was absent. The wastewater field was most difficult to detect



Dilution	S(psu)	S_A
83:1	32.946	1.20
100:1	33.013	1.00
125:1	33.079	0.80
150:1	33.124	0.67
167:1	33.145	0.60
175:1	33.155	0.57
200:1	33.179	0.50
250:1	33.213	0.40
333:1	33.246	0.30
500:1	33.279	0.20
1000:1	33.313	0.10

Fig. 2. Calculated salinity anomaly (S_A) and computed salinities values for different dilutions based on a mean salinity of 33.346 psu.

when surface salinities decreased substantially during episodes of heavy rainfall and subsequent storm runoff. This effectively negated the effectiveness of salinity anomaly by decreasing Bay-wide mean salinity. In these instances, transmissivity, DO, and temperature provided useful information on the location of the wastewater field.

The size of the wastewater field in Santa Monica Bay followed seasonal trends relative to the development and duration of seasonal density stratification. The farfield was larger than the nearfield and could extend many kilometers beyond the nearfield. In early summer, the wastewater field was smaller and generally was detected at stations nearest the outfall, but became larger and more extensive as summer progressed. Usually the wastewater field reached the maximum size and concentration by October after eight months of stratified conditions. Within the nearfield, salinity was low and wastewater dilution, estimated from salinity anomaly, was below 125:1. In October the farfield was pervasive, clearly extending beyond the survey area boundaries more than 15 km from the outfall. Following maximum development, the wastewater field quickly reduced in size and moved deeper in the water column as density stratification deepened. Once stratification eroded, only the nearfield was detected either close to the outfall or as a surfacing plume. When stratification was reestablished, the wastewater field became easier to identify but was often confounded in spring by the presence of rain induced low surface salinities. Direction of movement was highly variable throughout the

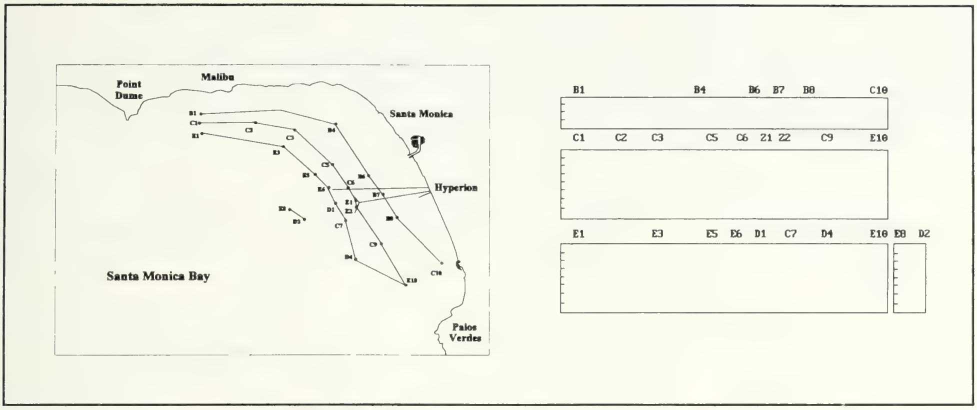


Fig. 3. Location of transects used for water quality plot contours with an example of an empty graphics box.

year and not related to any seasonal trend. The degree to which the location and size of the wastewater field varied from week to week was surprising.

To illustrate the weekly changes and the seasonal development of the wastewater field, salinity anomaly values were reconfigured in three shades of grey to represent the nearfield and farfield in this report. Three transects in the Bay were selected to provide a two-dimensional representation of the nearfield (depicted in black, $S_A > 0.80$), farfield (depicted in gray, S_A ranging from 0.40 to 0.80), and background (depicted in white, $S_A > 0.40$) (Fig. 3). Date notation indicates the respective survey year, month, and week; thus, 89Jul1 refers to the first weekly survey of July in 1989. Two years representing entirely different weather settings, a drought year, 1989–90, (Fig. 4a–d) and a wet year, 1991-92 (Fig. 5a–d) are presented to compare and contrast effects of rainfall on our ability to detect the wastewater field.

1989–90.—The sampling year began in July with summer conditions of shallow and strong density stratification overlying the submerged wastewater field. An example of the highly variable movement of the wastewater field in Santa Monica Bay is visible during the first four weeks of the year (Fig. 4a). Direction of movement was detected during the first week of the year as downcoast (C9) and offshore (D4) from the outfall, then shifted within two weeks to a centralized location over the outfall (Z1 and Z2) with a component of nearshore movement (B7). By the fourth week the wastewater field was detected upcoast and offshore (C5, E5, and E6) and a secondary field was present in the southern portion of the Bay (D4 and E10). This same variability in movement continued with the field contracting and enlarging in size throughout the ensuing weeks. The farfield generally followed the nearfield pattern but on a larger scale. A unique event occurred during the fourth week of September when the nearfield burst through density stratification to surface at the outfall stations (Z1 and Z2) and a nearshore station (B7).

In the next series of plots (Fig. 4b) the same variable wastewater field direction of movement continued with cooler surface temperatures, deeper stratification, and warmer bottom temperatures typical of fall. The fourth week of October provides an excellent example of a plume rising to neutral buoyancy as it is

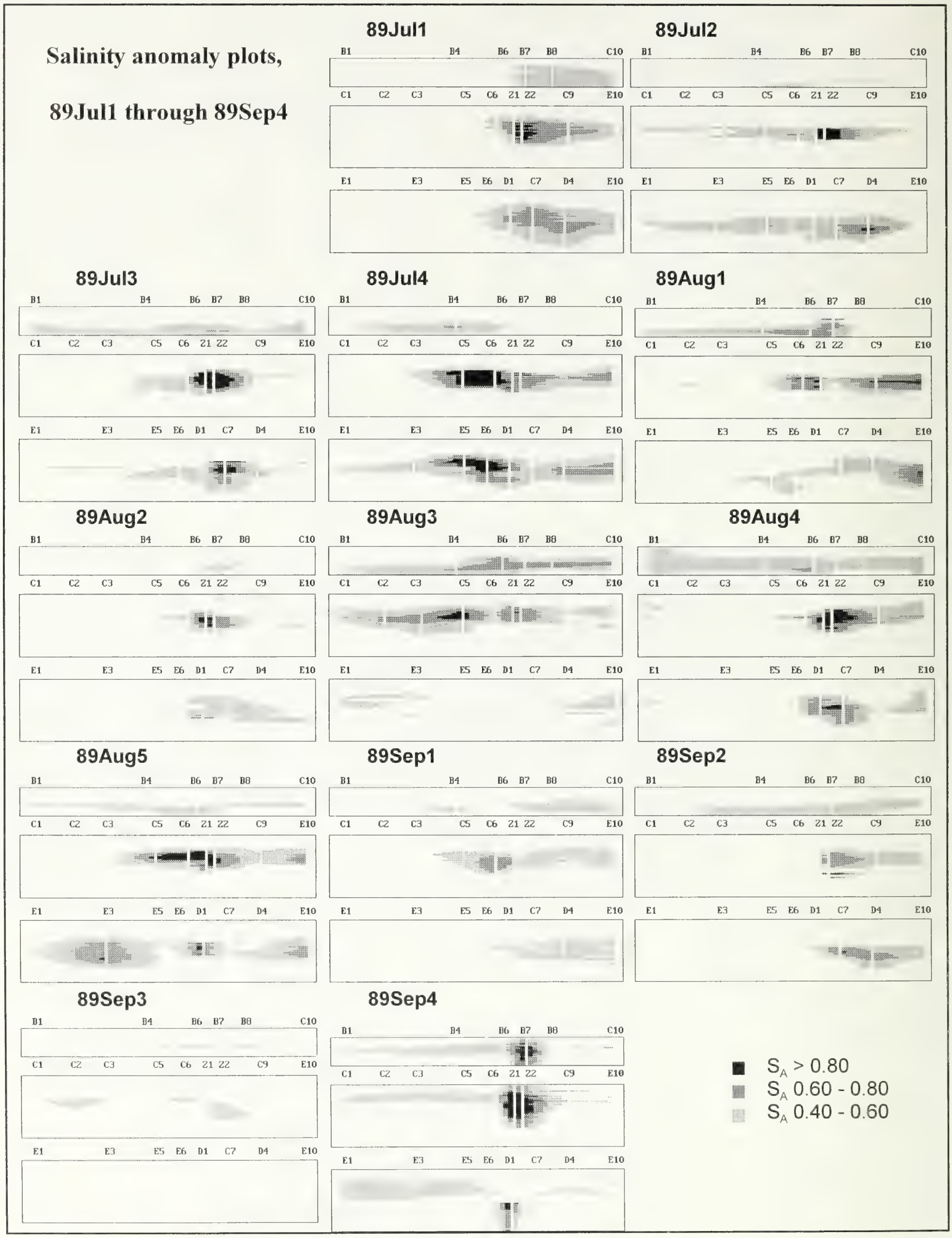


Fig. 4a. Salinity anomaly plots depicting nearfield (Black, $S_A > 0.80$) and farfield ($S_A = 0.40$–0.80) locations for surveys 89Jul1 through 89Sep4.

transported from the outfall. Beginning in mid-November (89Nov3), the wastewater field decreased in depth in response to the deepening density stratification. By the third week of December both the subsurface and a surfacing plume is visible as the nearfield was only partially submerged by weak stratification at 40–

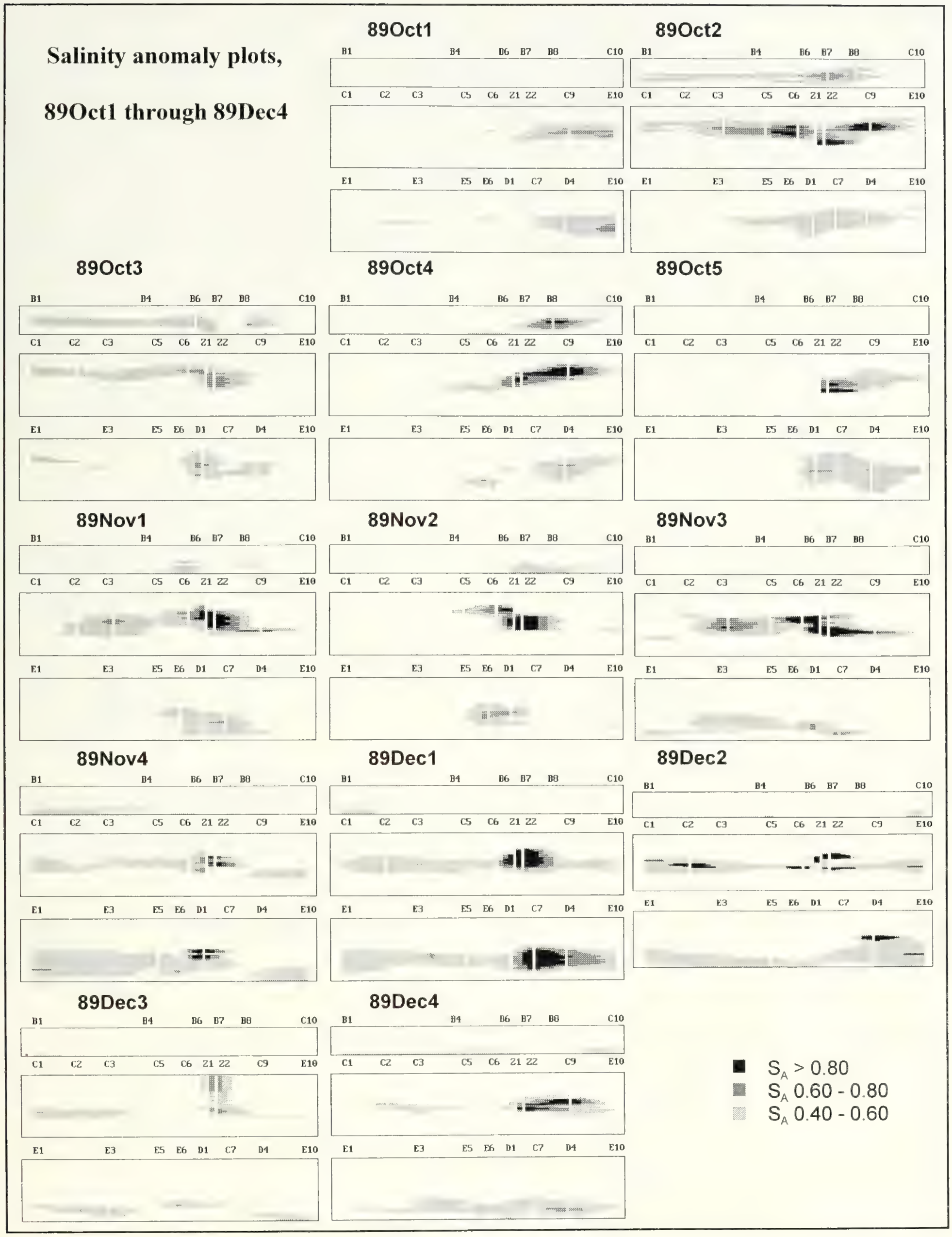


Fig. 4b. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 89Oct1 through 89Dec4.

60 m. Weak stratification, characteristic of late fall, continued through most of January resulting in a submerged field that lasted until the last week of the month (Fig. 4c).

The winter season produced many cold fronts with associated strong winds but

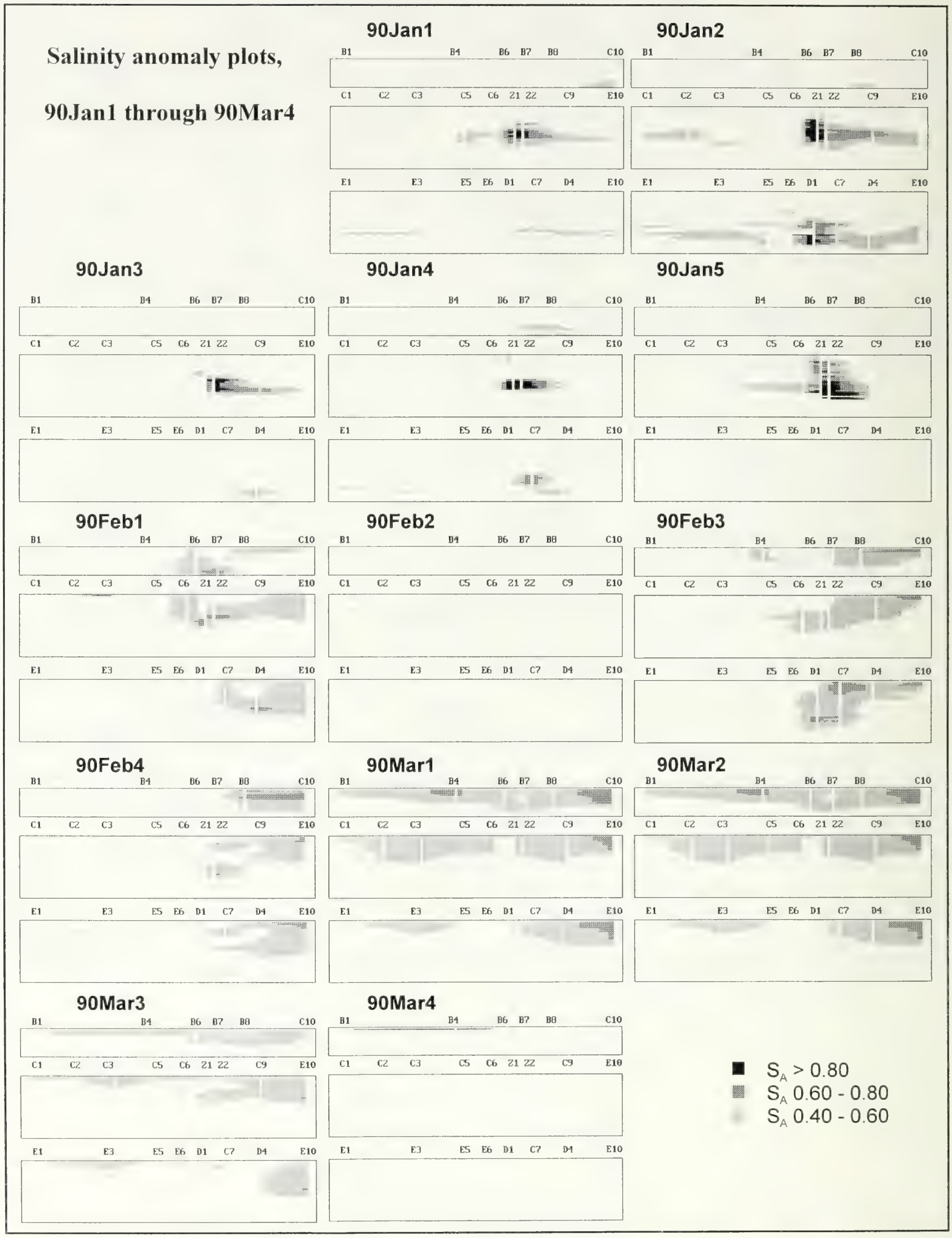


Fig. 4c. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 90Jan1 through 90Mar4.

little rainfall. The total rainfall for the 1989–90 season was 18.7 cm, less than half of the normal 37.9 cm (Los Angeles Times). Unstratified conditions developed by the second week of February following two cold fronts resulting in a surfacing wastewater field in the latter part of February (Fig. 4c). The wastewater field was

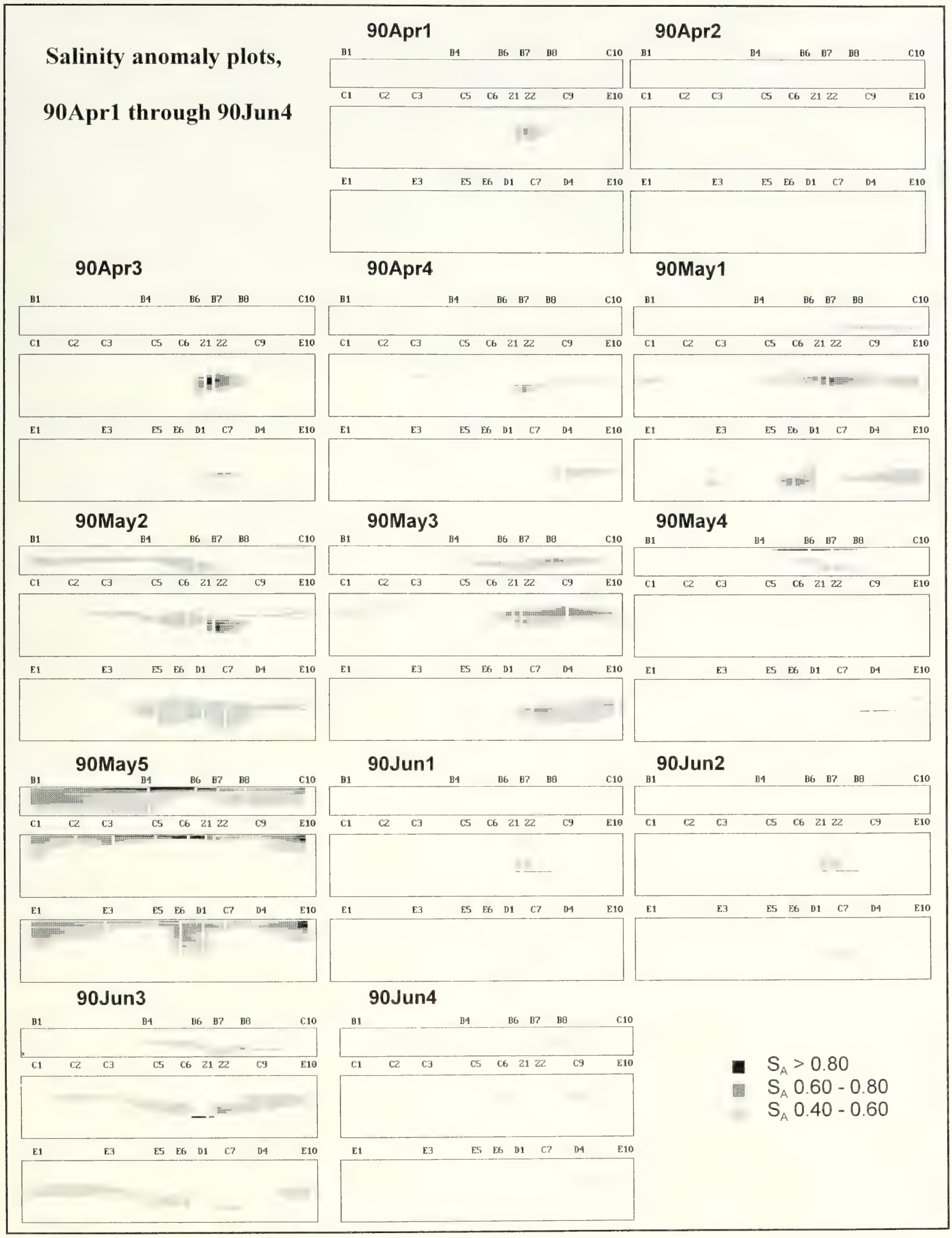


Fig. 4d. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 90Apr1 through 90Jun4.

not detected during the first three weeks of March when low surface salinities developed following two rain producing fronts. The associated heavy winds resulted in continued unstratified conditions and an acute upwelling event as indicated by low temperatures and high salinity. Weak stratification developed during the last week of March, but was insufficient to prevent a surfacing wastewater field.

Spring conditions developed with re-establishment of density stratification and the wastewater field became more easily detectable. In early April, the submerged wastewater field remained small, situated mainly at the outfall stations (Z1 and Z2) (Fig. 4d). The wastewater field gradually increased in size as stratification remained in place and extended to stations beyond the outfall by May. Another apparent upwelling event occurred between the fourth and fifth week of May as indicated by low temperature and high salinity. Two weeks later, apparent downwelling occurred following tropical weather causing high temperature and low salinity. Daily afternoon onshore winds resumed and chronic upwelling took place as temperatures gradually decreased and salinity gradually increased for the remainder of the month.

1992–93.–Summer began with low surface salinities persisting from the 1991–92 rainfall. Density stratification during these surveys was well established and spring upwelling had ceased. The wastewater field was submerged, generally well defined, and, as during 1989–90, varied in direction of movement (Fig. 5a). The nearfield was detected most frequently at stations located along the discharge 60-m isobath (C5, C6, and C7) at distances up to 5.3 km from the outfall. September illustrates both the variability of the direction of movement plus variability in the size of the wastewater field. During the first three surveys, a fairly sizeable field changed direction of movement from onshore to upcoast to offshore, then diminished in size by the fourth survey and enlarged to a pervasive field throughout the Bay during the fifth survey of September.

The presence of a large wastewater field continued for the following six weeks, moving deeper in the water column as density stratification deepened with the onset of fall conditions (Fig. 5b). It reached maximum size by October and continued this way until November. During this time a large, subsurface lense of low salinity water, with salinity anomaly values indicating wastewater nearfield (0.4–0.6), covered large portions of the Bay. For example, during the first survey in October, the nearfield covered 12 stations in all directions from the outfall (Z1 and Z2); 17.4 km upcoast to C2; 2.2 km downcoast to C7; 2.7 km onshore to B7; and 7.5 km offshore to E6. The field became smaller in late November and early December as density stratification moved deeper in the water column and weakened.

The first winter storm occurred between the first and second surveys of December initiating an unusually wet winter that resulted in 69.5 cm of rainfall (Los Angeles Times). The water column became unstratified after the first winter storm, a condition that continued through March. During this time the wastewater field was rarely visible (Fig. 5c). Low surface salinities formed in the Bay in January following the heaviest rains and persisted through March. The deviation of salinity at the surface was sufficient to cause the signal for the nearfield to weaken and appear as a farfield (grey color in the plots). A wastewater field was identified only during the first survey of March as a small field positioned below the low surface salinity layer in the vicinity of the outfall. During this time, identification of the wastewater field was augmented by visual inspection of color plots for areas with lowered DO, transmissivity, and/or temperature.

Weak stratification was established by the fifth week of March, signalling the

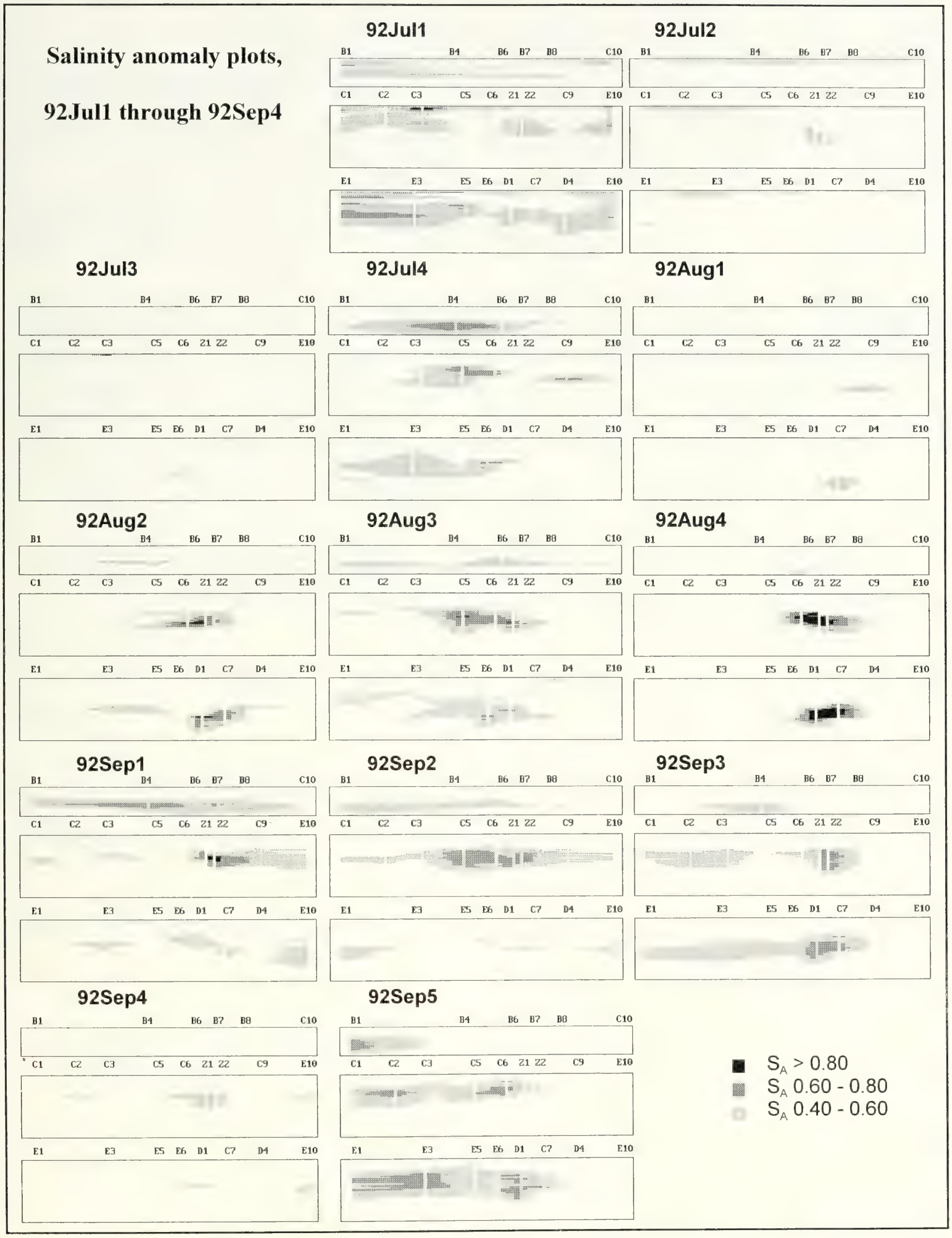


Fig. 5a. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 92Jul1 through 92Sep5.

start of spring, but the wastewater field was not readily visible until April (Fig. 5d). Low surface salinity persisted through the end of the year but with diminishing intensity. The wastewater field was visible immediately after stratification reestablished. During this time it was localized at the outfall and was smaller than

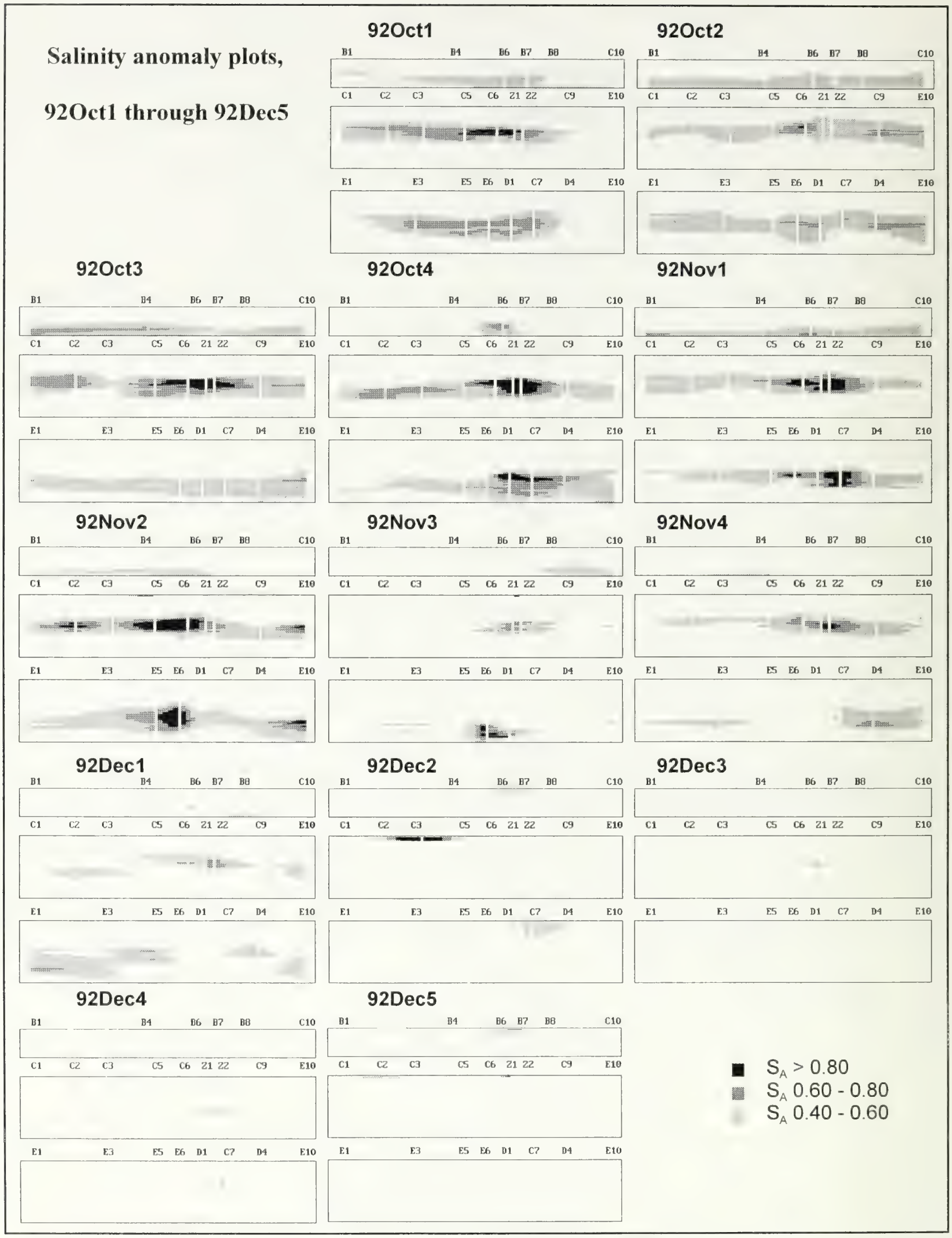


Fig. 5b. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 92Oct1 through 92Dec5.

the nearfields surveyed during the previous summer and fall. Movement of the wastewater field was highly variable, similarly to summer and fall. An unusually late rainstorm occurred in early June resulting in a renewed appearance of low surface salinities that month.

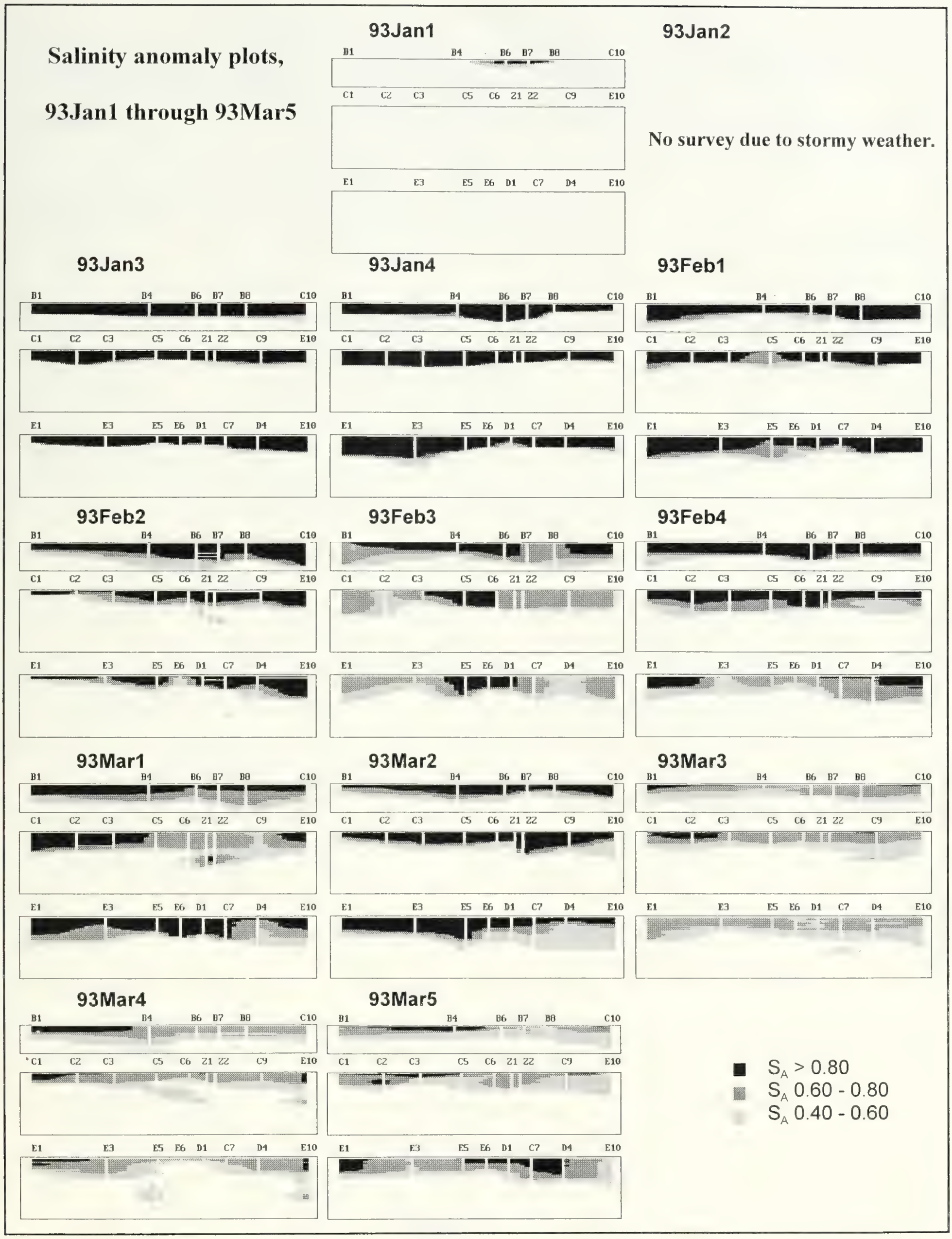


Fig. 5c. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 93Jan1 through 93Mar5.

Discussion

We were able to effectively determine the location of the wastewater field and follow seasonal development of oceanographic processes over nearly seven years by employing fairly simple means for analyzing CTD data. In an earlier study,

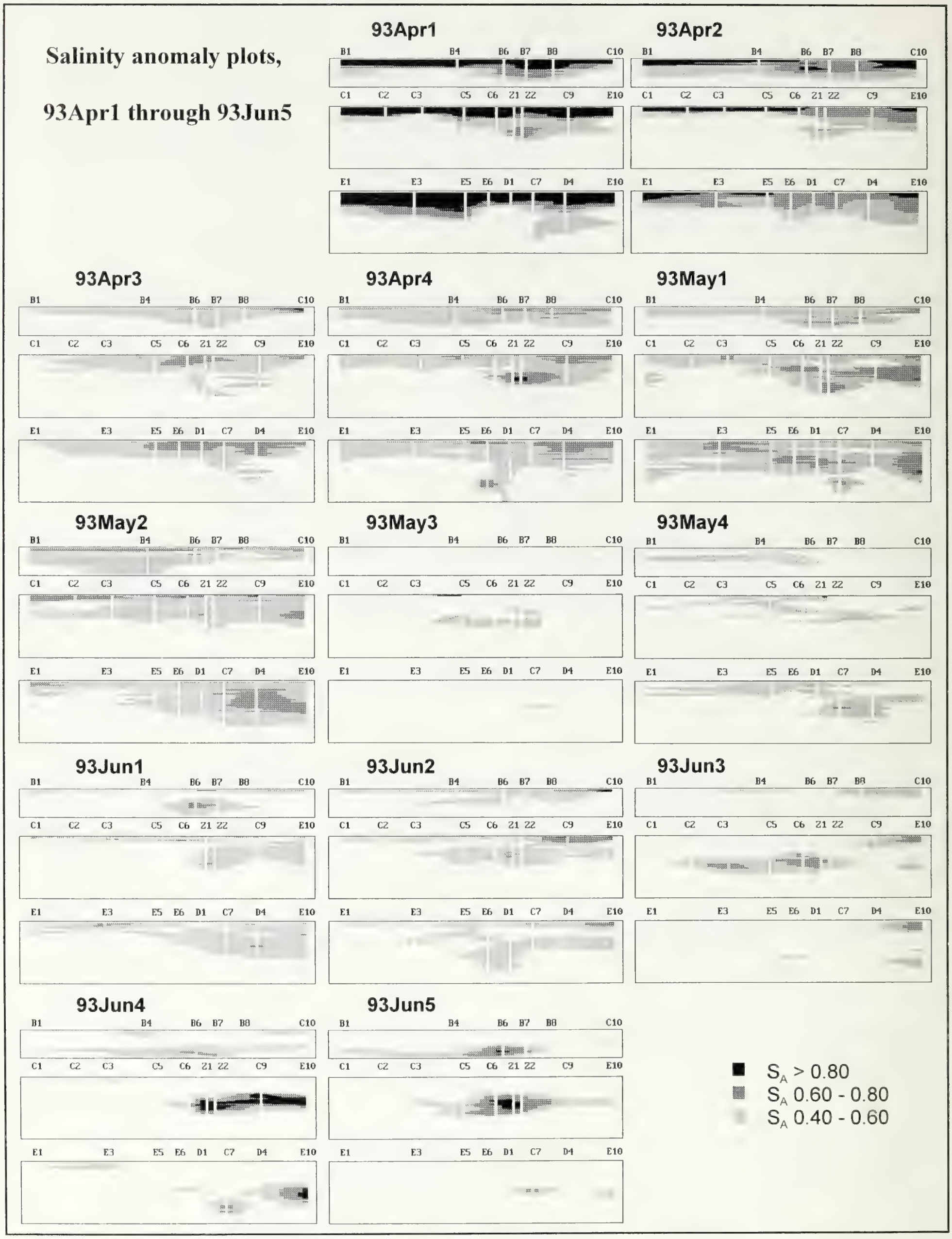


Fig. 5d. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 93Apr1 through 93Jun5.

Wu et al. (1994) were able to unambiguously identify the location of the effluent field at White's Point by employing a quasi-objective procedure utilizing threshold criteria for combinations of salinity, turbidity, and chlorophyll fluorescence. Although our data set lacked chlorophyll fluorescence measurements that would enable us to employ similar methods, salinity measurements provided sufficient information for identifying the effluent field. Temperature, transmissivity, and dissolved oxygen augmented detection of the wastewater field, however, these parameters were not correlated with salinity anomaly at this time. Our long-range goals include utilizing multiple parameters in conjunction with salinity, in particular coliform and ammonia data, to better determine the location of the wastewater field.

Calculation of the salinity anomaly, initially devised to eliminate temporal fluctuations in salinity, enabled us to estimate dilutions of effluent in situ. Albeit sources of error such as variable background salinity were not included in the calculation, we believe that salinity anomaly works well to reveal patterns of wastewater field distribution. For example, the resulting estimated dilutions revealed that dilutions as low as 125:1, described as nearfield in this report, often occurred at stations 2 km from the outfall and less commonly at distances up to 8 km. These distances extend well beyond the zone of initial dilution (ZID) which is a theoretical 60-m boundary surrounding the outfall diffuser in which the turbulent mixing of initial dilution takes place. Outside this boundary the discharged effluent reaches neutral buoyancy with continued dilution of the wastewater field occurring from ambient turbulence at a much slower rate (Roberts et al. 1989a, 1989b). Surprisingly, salinity anomaly values measured in non-outfall nearfields often were higher than values at outfall stations indicating that a higher concentration of the wastewater field was present outside the ZID.

The presence of wastewater fields several kilometers from the outfall supports the concept that dispersion of the wastewater field following initial dilution is a much slower process. These wastewater fields were positioned higher in the water column than those of similar salinity characteristics at the outfall stations (Z1 and Z2) indicating that the initial turbulent mixing was complete and that neutral buoyancy had been achieved. Wu et al. (1994) also detected highly concentrated effluent several kilometers from the source of discharge. They noted that dilution of the effluent plume did not precisely follow that theorized by Roberts et al. (1989a) and attributed the effect to currents and the complicated three dimensional structure of effluent plumes. The fact that higher concentrations of the wastewater field have been detected outside the ZID illustrates the complexity of the dilution process and indicates that initial dilution may not be confined to within several hundred meters of the outfall as described by Roberts et al. (1989b).

The highly variable wastewater field movement demonstrates the complexity of currents that exist in the Bay as described by Tareah J. Hendricks of SCCWRP (personal communication) and Hickey (1992, 1994). Hendricks concluded that currents in the Bay were chaotic after conducting a survey in which he deployed current meters at various depths and locations in Santa Monica Bay. He provided us with a compilation of his data into graphical representations that show direction of movement and speed which we summarized by week for each mooring. When compared to CTD surveys conducted during the same time, a strikingly similar pattern between current patterns and distribution of the wastewater field appears. In the example provided in Table 1, two current meters were placed into service (6 September 1989) at the same time a CTD survey was conducted (6–7 September 1989). On that day, currents were measured as going upcoast at both depths, 35 m and the bottom, and the wastewater field was visible upcoast (Fig. 4a). In each

Table 1. Current direction as indicated by summarized results from a single mooring near the City's outfall compared to direction of wastewater movement detected by the CTD.

	Current meter data		CTD data	
	Current direction		Nearfield direction	
Date	35 m	Bottom	Sampling date	Stations
6 Sep 89	Upcoast	Upcoast	6–7 Sep 89	C6
13 Sep 89	Downcoast-onshore	Downcoast-onshore	12–13 Sep 89	Z2, C7–D4
20 Sep 89	Upcoast-onshore	Upcoast-onshore	19–20 Sep 89	C6, B6
27 Sep 89	Confused Double gyre	Confused Double gyre	26–27 Sep 89	C6–Z2, B7, D1

successive week, the nearfield was detected at stations located in the direction that currents were moving. During the last week of the survey, currents were very confused and the nearfield was detected in several directions; upcoast (C6), onshore (B7), and offshore (D1) (Fig. 4a).

In conclusion, nearly seven years of weekly CTD surveys enabled us to develop a detailed picture of anthropogenic and natural events in Santa Monica Bay that will serve as a benchmark for subsequent programs. Notably, the Hyperion outfall is functioning as a large underwater freshwater river that interacts with natural processes as it is transported erratically throughout the Bay. Additionally, the data support theories of wastewater plume behavior as described by Wu et al. (1994).

Acknowledgments

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Toxicity of Dry Weather Flow from the Santa Monica Bay Watershed

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Abstract.—A significant source of contaminants to Santa Monica Bay is the daily discharge of 10–25 million gallons of urban runoff from approximately 70 storm drains. Research conducted in 1990–93 examined the toxicity of dry weather flow from Ballona Creek and three other drains discharging into Santa Monica Bay. Toxicity tests were conducted using sensitive life stages of purple sea urchins, red abalone, and giant kelp. Spatial and temporal variations in toxicity were observed. Sea urchin sperm and abalone embryos were more sensitive than kelp spores, with toxic effects produced by ≥5.6% dry weather flow. Preliminary toxicity identification evaluations indicated that the constituents causing toxicity in dry weather flow are variable.

Urban runoff consists of two major components: stormwater resulting from rainfall and dry weather flow. Dry weather flow occurs daily in some storm drains, with an estimated 40–90 million liters per day flowing into Santa Monica Bay through approximately 70 outlets that empty onto or across beaches (LAC, DPW 1985; SMBRP 1994). The contribution of dry weather flow to the total volume of runoff into Santa Monica Bay varies, depending upon rainfall patterns, accounting for about 30% of the total (NRC, COWT 1984). While the chemical composition and toxicity of sewage and industrial effluent discharges into the ocean are well characterized (SCCWRP 1990a, b) and subject to strict regulations (SWRCB 1990), studies of runoff are much more limited (SMBRP 1994; SCCWRP 1990c). A wide variety of chemical contaminants, including heavy metals, petroleum compounds, pesticides, and PCBs have been detected in samples of dry weather flow and stormwater (SCCWRP 1990c; Suffet et al. 1993; SMBRP 1994). It is estimated that runoff is responsible for about one-fourth of the current contaminant inputs to Santa Monica Bay (SMBRP 1994).

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Runoff usually enters the ocean at the beach, harbors, or bays, where the chances for interaction with sensitive environments (e.g., wetlands) or human contact are high. Though dry weather flow represents a chronic source of pollution to Santa Monica Bay's coastal environment, the biological effects are poorly known. This paper presents the results of recent toxicity studies of dry weather flow from several storm drains discharging into Santa Monica Bay. The objectives of this research were to measure the effects of dry weather flow on sensitive marine organisms, examine variability between sites or with time, and identify the toxic components.

Methods

Sampling Locations and Procedures

Samples were collected from four storm drains in the greater Los Angeles (Calif.) area (Fig. 1). Drainage area varied for each site, ranging from 25,952 ha for Ballona Creek to 1,123 ha for Ashland (unpublished UCLA data). Land use was primarily residential within each drainage (52–63% of total area). An additional criterion guiding station selection was the presence of dry weather flow in each drain.

Dry weather flow.—Samples of dry weather flow were collected during two separate research programs. In the first study, samples were collected in December 1990 and February 1991 from Ballona Creek only. In the second study, 1–6 samples were collected from the four drains between August 1992 and January 1993. Samples from Ballona Creek and Sepulveda Channel were obtained from the middle of the concrete drainage channels. At Pico-Kenter, samples were collected from a well installed to divert dry weather flow into the sanitary sewer. Samples from the Ashland drain were obtained from a sump near the beach. The Ashland site received seawater inputs at high tide, the other three sampling locations were above the tidal prism.

Samples were obtained by immersing a 1-L glass bottle (1990–91) or stainless steel bucket (1992–93) in the discharge. Water depth was generally shallow and it is likely that the surface microlayer was collected with the sample. Morning and afternoon samples were collected in 1992–93 and usually composited before toxicity testing. All samples were placed in coolers and stored at 4°C until further analysis.

Receiving water. Surface water from six locations within the area where Ballona Creek effluent mixes with receiving water from Santa Monica Bay (between end of concrete channel and Marina del Rey breakwater, Fig. 1) were collected in February 1991. Samples were obtained from the center of the channel by submerging a glass bottle approximately 0.2 m below the surface. Conductivity measurements were used to determine the percentage of runoff in each sample. The surface microlayer was not included in these samples.

Chemical Analysis

Samples collected in 1992–93 were analyzed for the following water quality parameters according to standard methods (APHA 1989): ammonia (method 4500-NH_3.F), total dissolved solids (TDS, method 2540.C), total suspended solids (TSS, 2540.D), chemical oxygen demand (COD, method 5220.B), dissolved or-

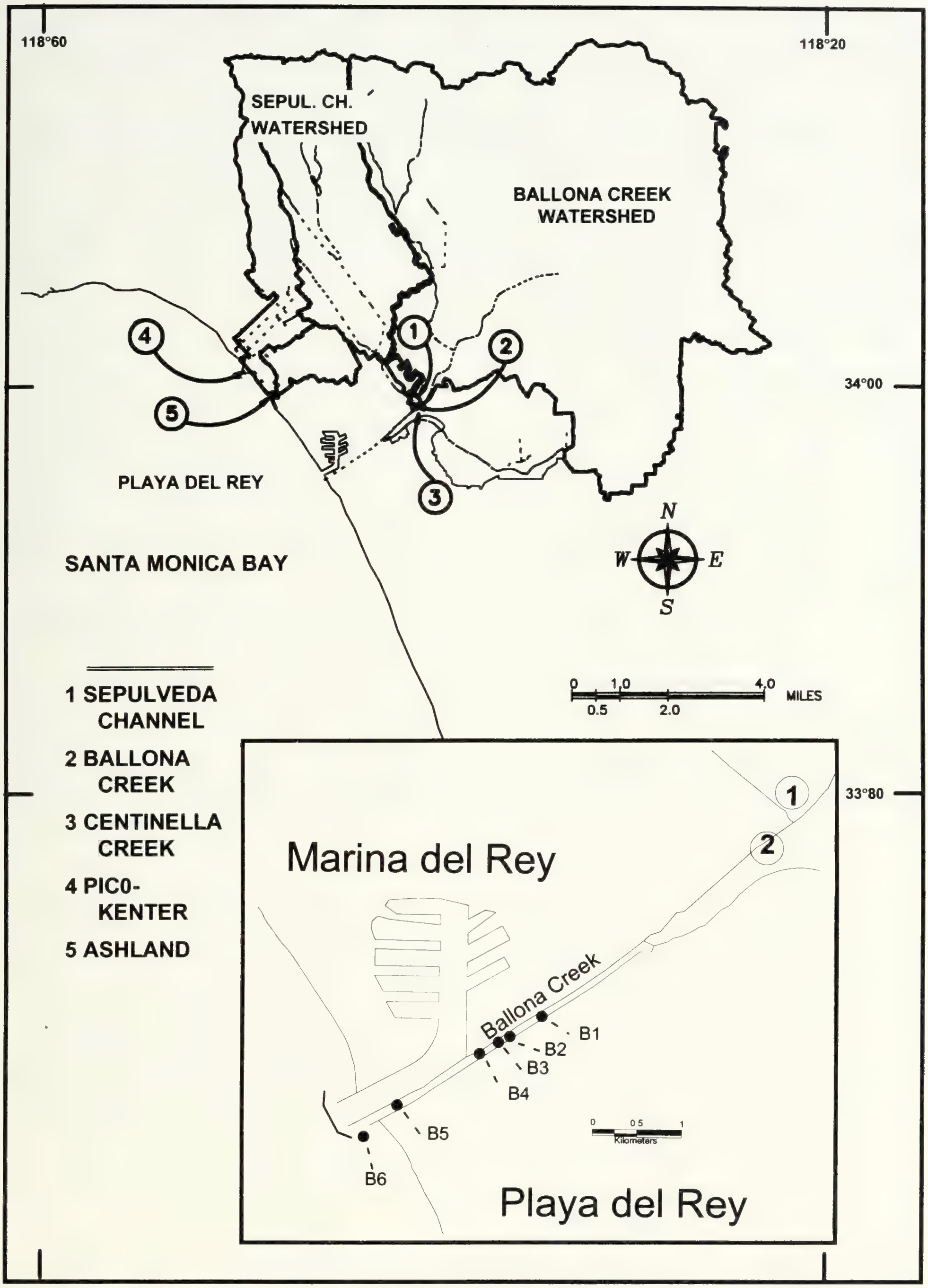

Fig. 1. Location of storm drain sampling sites and watershed boundaries (thick lines). Broken lines indicate larger storm drain channels. Inset shows locations of sampling sites for receiving water (B1–B6), Sepulveda Channel (1) and Ballona Creek (2).

ganic carbon (DOC, method 5310), turbidity (method 2130.B), and dissolved oxygen (method 4500-OG).

Toxicity Assessment

Samples collected in 1992–93 were passed through a 1.0 μm glass fiber (Whatman GF/B) and adjusted to a salinity of 34 g/kg by addition of brine before toxicity testing. Toxicity tests conducted in 1990–91 used unfiltered samples without salinity adjustment. Filtered natural seawater was added to all samples to produce four or five test concentrations ranging from 2–56% effluent. Three or four replicates of each concentration were tested. Toxicity tests were initiated within 24 hours of sample collection.

Short-term chronic toxicity tests using three species of marine organism (sea urchin, abalone, kelp) were used to evaluate the toxicity of dry weather flow samples. These methods are among those recommended in the State of California's Ocean Plan (SWRCB 1990) for measuring the toxicity of discharges into the marine environment. All tests were conducted at 15°C and a salinity of 34 g/kg. Concurrent reference toxicant tests using copper chloride or zinc sulfate were included to document temporal variations in test sensitivity. A summary of the toxicity test methods follows; additional method information is presented in Lau et al. (1994).

Sea urchin fertilization test.—All samples were tested for effects on the fertilization of sea urchin eggs using modifications of the method described by Dinnel et al. (1987). Sea urchins were induced to spawn through injection of KCl, sperm was collected dry (without addition of seawater), and stock solutions of sperm and eggs prepared. The test was conducted by adding sufficient sperm to 10 mL volumes of sample to produce a sperm : egg ratio of 200–400:1. Eggs were added after 60 minutes, given 20 minutes for fertilization, and preserved with formalin.

Abalone embryo development.—Embryos of the red abalone (*Haliotus rufescens*) were exposed to 1992–93 storm drain samples according to the method described by Anderson et al. (1990). Abalone spawning was induced by exposure to a hydrogen peroxide solution. Newly fertilized eggs were added to 200 mL of test sample and allowed to develop for 2 days. The resulting embryos were preserved with formalin and examined microscopically.

Giant kelp spore germination and growth.—Toxicity tests with giant kelp (*Macrocystis pyrifera*) spores were conducted according to procedures described by Anderson et al. (1990). Zoospore release was induced by desiccation of kelp blades containing reproductive spores (sporophyll). Spores were added to beakers containing 200 mL of sample and glass microscope slides. Slides were removed after 48 hours exposure under controlled light levels (50 $\mu Em^{-2}sec^{-1}$), preserved, and examined to assess spore germination rate and gametophyte length.

Toxicity Characterization

Two samples were collected from Ballona Creek for preliminary toxicity identification evaluation (TIE). Morning and afternoon grab samples were collected on December 14, 1992 and January 12, 1993. The sea urchin fertilization test was used to select the most toxic sample for each day. Phase I TIE manipulations were conducted the following day and consisted of C18 solid phase extraction (SPE), EDTA addition, and sodium thiosulfate addition following the recommendations of Norberg-King et al. (1992). All procedures were conducted at the

Table 1. Median effect (EC50) and no observed effect (NOEC) concentrations for dry weather flow samples collected from multiple sites in 1992. Toxicity was measured using abalone (*Haliotus rufescens*) embryo development, sea urchin (*Strongylocentrotus purpuratus*) fertilization, and giant kelp (*Macrocystis pyrifera*) spore germination/length tests.

		NOEC (% sample)				EC50 (% sample)			
Site	Date	Abalone	Kelp germination	Kelp length	Urchin	Abalone	Kelp germination	Kelp length	Urchin
Ashland	8/24/92	<5.6	18	18	10	6.8	32	>56	17
	9/29/92	nc[a]	nc	nc	5.6	nc	nc	nc	14
	10/12/92	5.6	5.6	5.6	<5.6	10	22	50	<5.6
Ballona	9/8/92	≥56	≥56	≥56	<5.6	>56	>56	>56	14
	9/29/92	nc	nc	nc	12[b]	nc	nc	nc	>56
	10/12/92	≥56	≥56	≥56	≥56	>56	>56	>56	>56
Pico-Kenter	8/24/92	18	≥56	≥56	≥56	42	>56	>56	>56
	9/29/92	nc	nc	nc	≥56	nc	nc	nc	>56
	10/12/92	12	≥56	25	25	21	>56	>56	41
Sepulveda	9/8/92	≥56	≥56	≥56	10	>56	>56	>56	nc

[a] Value could not be calculated due to poor test results or unusual dose-response curve.

[b] NOEC can also be stated as >56% since 56% concentration was not significantly different from brine control. A NOEC of 12% is felt to be more appropriate since the 56% brine control was toxic, making the accuracy of the results for 56% sample questionable.

ambient pH of the sample and are fully described by Lau et al. (1994). Toxicity of the treated samples, blanks, and untreated stored sample was measured the day after manipulation (approximately 48 hours after collection) using the sea urchin fertilization test.

Data Analysis

The no observed effect concentration (NOEC) was determined for each treatment by Dunnett's multiple comparison test (Zar 1984). Data for the sea urchin and abalone tests were arcsine transformed before statistical testing. The concentration producing a 50% toxic response (EC50) was calculated using probit analysis. Data from different experiments were normalized to the control response to facilitate comparisons between species. This was accomplished by expressing the result for a specific sample as a percentage of the average control response for the experiment.

Results

Toxicity Patterns

Results of the multiple site comparisons in 1992–93 show that toxicity was present in at least one sample from each of the four locations sampled (Table 1). There were differences in test response between locations and test species, however.

Species-specific patterns.—Examination of the dose-response plots for samples from Ballona Creek and Pico-Kenter show that each test species responded differently to some samples (Fig. 2). The sea urchin fertilization test was the only method to detect toxicity in the September 8, 1992 sample from Ballona Creek.

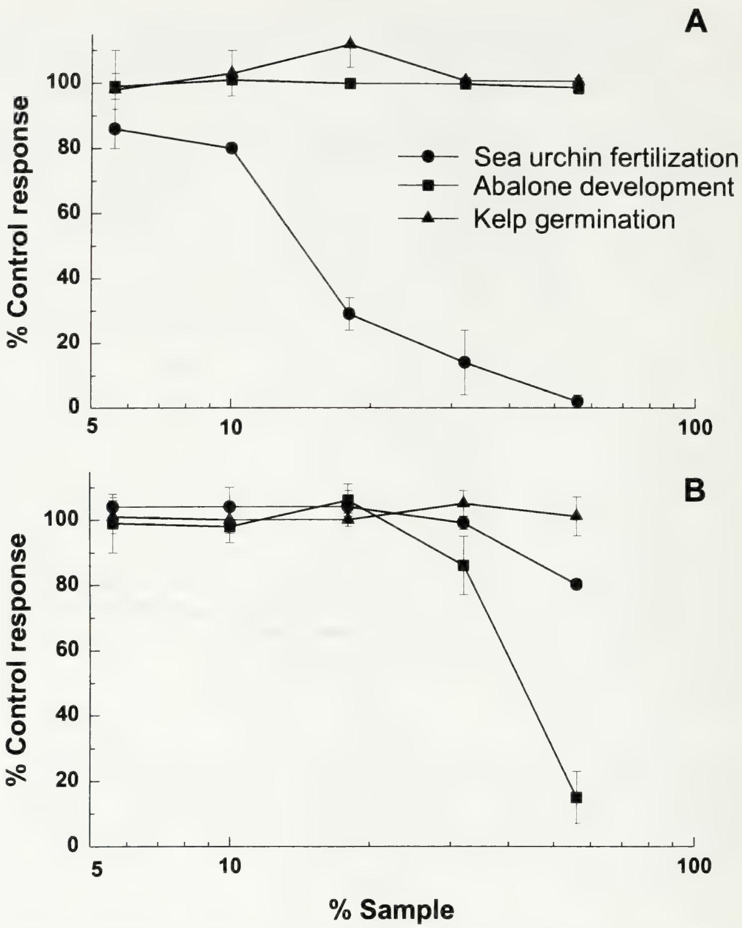

Fig. 2. Toxicity test responses to various concentrations of dry weather storm drain effluent. Test results (mean and standard deviation) have been normalized to the control response. A: Ballona Creek composite sample collected September 8, 1992. B: Pico-Kenter composite sample collected August 24, 1992.

For Pico-Kenter, abalone development was more sensitive than sea urchin fertilization or kelp germination/growth for both samples analyzed with multiple species. The kelp test was the least sensitive of the three test methods for all sites examined (Table 1).

Spatial variability.—The NOEC and EC50 data (Table 1) identify Ashland as consistently the most toxic site. Toxicity was detected by all three test methods for the Ashland samples.

Temporal variability.—The sea urchin fertilization test was used to evaluate the greatest number of samples and provides the best indication of temporal variability in toxicity. Toxicity units (TU, 100/EC50) were calculated in order to facilitate comparisons of relative toxicity between samples (Fig. 3). Substantial variations in toxicity were present between multiple samples from Ashland and Ballona Creek. Though the Ashland sample was consistently toxic, relative toxicity varied more than three-fold.

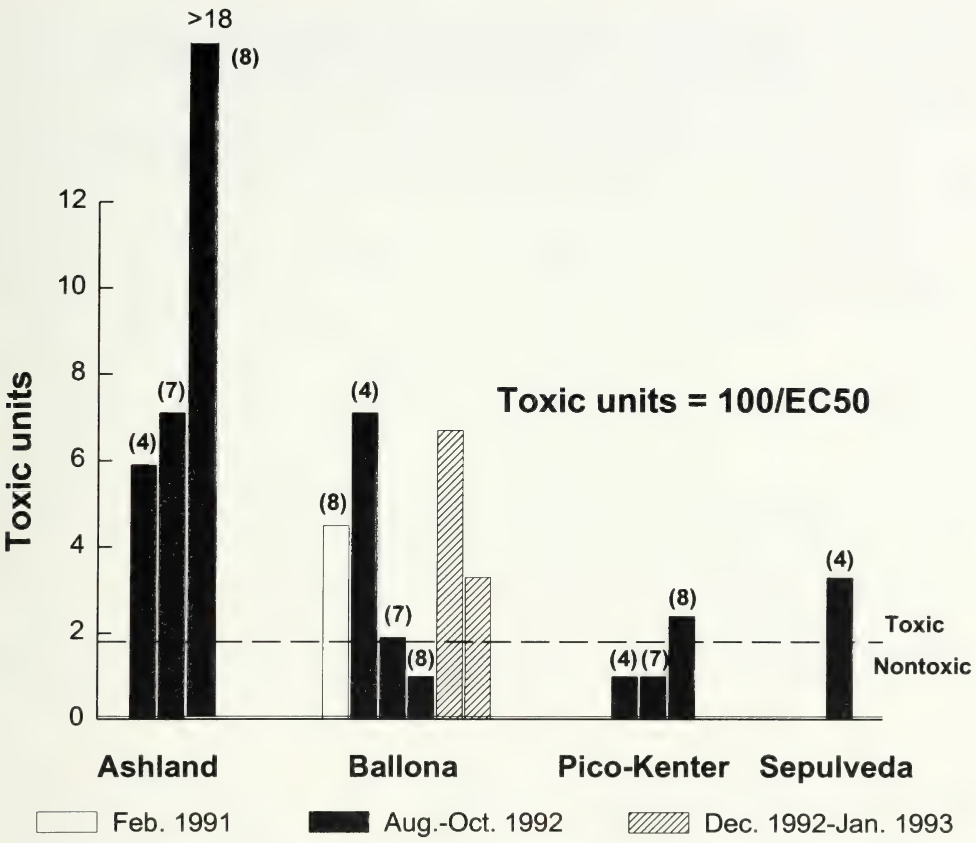

Fig. 3. Variability in sea urchin (*Strongylocentrotus purpuratus*) fertilization test results with time and storm drain location. Results of concurrent reference toxicant (copper) tests for each set of samples are shown in parentheses.

Even greater temporal variation was present between Ballona Creek samples. Three samples taken within the span of approximately one month ranged from strongly toxic (7 TU) to nontoxic (<2 TU). No long-term trends were evident at Ballona Creek; toxicity of a sample collected the previous year (February 1991) fell within the range measured in 1992–93 (Fig. 3). Results of reference toxicant (copper chloride) tests varied by about a factor of two, indicating that variations in fertilization test sensitivity, though present, were within acceptable limits. Variations in reference toxicant response did not correspond to the temporal or spatial variability in dry weather flow toxicity (Fig. 3).

General Constituents of Dry Weather Flow

Water quality measurements indicate variations in effluent composition between sites despite similar land use distributions (Table 2). Samples from Ashland usually had the poorest water quality. For example, Ashland had higher levels of suspended solids, chemical oxygen demand, dissolved organic carbon, turbidity, and ammonia than the other sites. Dissolved oxygen concentration was also low at Ashland and a sulfide odor was usually present. The ocean discharge pipe for

Table 2. Study site land use and physical/chemical characteristics of dry weather flow samples used in 1992–93 toxicity tests. Data are means and standard deviations. Ballona Creek means include data from two samples used for toxicity identification evaluations. See footnotes for sample collection dates.

Parameter	Ashland[a]	Ballona[b]	Pico-Kenter[a]	Sepulveda[c]
Land use (% of area)[d]				
Residential	55	63	52	58
Commercial	4	11	16	9
Light industrial	2	4	13	1
Public, open, or other	39	22	19	32
pH	7.6 ± 0.2	8.5 ± 0.4	7.6 ± 0.1	8.7
COD (mg/L)	252 ± 64	52 ± 24	88 ± 38	73
Dissolved oxygen (mg/L)	1.6 ± 0.3	>15	6.6 ± 0.8	>15
TDS (mg/L)	6,058 ± 4,045	1,903 ± 1,204	1,493 ± 841	4,071
TSS (mg/L)	299 ± 476	59 ± 75	103 ± 71	13
DOC (mg/L)	34 ± 14	9 ± 3	15 ± 1	16
Ammonia (mg/L as NH_3-N)	0.76 ± 0.46	0.22 ± 0.29	0.11 ± 0.10	0.06
Turbidity (NTU)	138 ± 209	42 ± 62	30 ± 14	4

[a] Samples collected on 8/24/92, 9/29/92, and 10/12/92.

[b] Samples collected on 9/8/92, 9/29/92, 10/12/92, 12/14/92, and 1/19/93.

[c] Sample collected on 9/8/92.

[d] Ashland, Ballona, and Pico-Kenter data from UCLA and WCC (1992). Sepulveda data from unpublished information.

Ashland was often blocked by sand, creating stagnant conditions that may have been responsible for the degraded water quality.

Both Ashland and Sepulveda Channel had relatively high levels of total dissolved solids (TDS), but for different reasons. Tidal intrusion of seawater influenced TDS levels at Ashland, while permitted discharges of ion exchange regeneration waters affected Sepulveda Channel TDS.

Dissolved oxygen (DO) and pH were unusually high at both Ballona Creek and Sepulveda Channel. Ballona Creek samples collected in 1990–91 had a high pH (10.1). Elevated pH and DO probably resulted from the metabolic activity of algal mats which lined the bottoms of these open channels.

Toxic Components

pH.—Variations in pH did not influence the toxicity results shown in Figure 3 because the pH was adjusted to typical seawater values (7.9–8.3) before testing. Ballona Creek samples collected in December 1990 and February 1991 were also tested without pH adjustment. The high pH of these samples (10.1) substantially elevated the pH of test concentrations containing ≥10% effluent (Fig. 4). Strong effects on sea urchin fertilization were observed for these samples; 1990 and 1991 Ballona Creek samples had EC50s of 10% & 6%, respectively. Toxicity of the 1991 Ballona Creek sample was greatly reduced, but not eliminated by pH adjustment (Fig. 4).

Salinity.—No adjustments for altered salinity were made on the 1990–91 test samples. Substantial reductions in salinity (>3 g/kg) were present in samples containing ≥10% effluent. The results of concurrent salinity controls (deionized water substituted for effluent) indicated toxic effects were produced when salinity

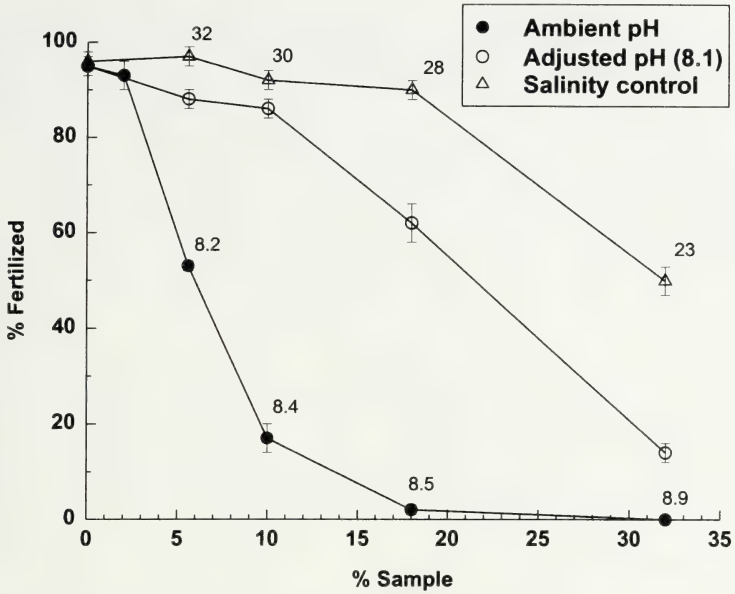

Fig. 4. Effects of reduced salinity and pH adjustment of a February 1991 Ballona Creek sample on sea urchin (*Strongylocentrotus purpuratus*) fertilization. Measured salinity and pH for selected treatments are indicated above the symbols.

fell below 28 g/kg (Fig. 4). The response of sea urchin sperm to pH adjusted Ballona Creek effluent was greater than that produced by salinity change alone.

Toxicity characterization.—Phase I TIE manipulations of two Ballona Creek samples produced variable results. Toxicity in the first sample (collected in December 1992), was partially removed by solid phase extraction and completely eliminated by thiosulfate addition (Table 3). Chelation by EDTA was not effective in reducing toxicity of the first sample. Solid phase extraction and thiosulfate

Table 3. Results of phase I TIE manipulations and water quality analyses of storm drain samples collected in December 1992 and January 1993 from Ballona Creek. The baseline sample represents stored effluent prior to TIE. Toxicity data are the mean of duplicates containing 56% storm drain effluent, water quality data represent single samples.

% fertilized after treatment			Water quality		
Treatment	12/92	1/93	Constituent	12/92	1/93
Baseline	15	16	pH	8.2	8.1
Chelation[a]	44	92	COD (mg/L)	70	37
Reduction[b]	99	10	TDS (mg/L)	3,810	829
Extraction[c]	76	20	TSS (mg/L)	174	97
			Ammonia (mg/L)	0.70	0.28
			Turbidity (NTU)	146	56

[a] Addition of 3 mg/L EDTA to sample.
[b] Addition of 10 mg/L sodium thiosulfate to sample.
[c] Solid phase extraction of 1 L sample using 1 g of C18 sorbent.

Table 4. Sea urchin (*Strongylocentrotus purpuratus*) fertilization toxicity test results for surface water samples from the mouth of Ballona Creek. Station locations are shown in Figure 1. Sample concentration was calculated from conductivity measurements.

	Station					
	B1	B2	B3	B4	B5	B6
Fertilization (%)	21	62	90	54	16	16
Dry weather flow concentration (%)	22	9	6	4	<1	<1

addition were ineffective when applied to the second sample (January 1993), while the toxicity was eliminated by EDTA.

Differences in TIE sample characteristics were also indicated by the water quality data. There were marked differences in water quality (e.g., TDS and turbidity) between the two TIE samples (Table 3).

Receiving Water Toxicity

Five of six receiving water samples from the mixing zone of Ballona Creek were toxic to sea urchin sperm (Table 4). The greatest toxicity was present in samples from both the upstream and downstream ends of the sampling area. Fertilization effects did not correspond to the amount of Ballona Creek effluent in the samples; the strongest toxicity was produced by water samples containing the highest (22%) and lowest (<1%) concentrations of dry weather flow (Table 4).

Discussion

The results presented here are preliminary since they are based on a limited number of stations and samples. But they are sufficient to allow us to evaluate the following questions.

Is it toxic?—Dry weather flow often causes toxicity at concentrations above about 6%, as indicated by the data presented in Table 1. Toxicity to marine invertebrates was found in at least one sample from each of the four sites investigated and was evident in samples collected from Ballona Creek over a span of two years. Adult forms of the test organisms (sea urchins and abalone) are not found in the immediate vicinity of these storm drains, although it is likely that the larval forms of similar species are present in nearby waters. The test data indicate the relative toxicity of dry weather flow, but may not accurately predict effects on specific resident species.

Previous research has shown dry weather flow from two local drainages to be toxic to marine bacteria (SCCWRP 1989). In this study, toxicity of a dry weather flow sample was greater than the average toxicity of storm runoff samples in Ballona Creek. Toxicity of a dry weather flow sample from the Los Angeles River sample was lower, but within the range of stormwater samples from the same location.

Results from the 1992–93 samples demonstrate multiple sources of variability. Toxicity showed both spatial and temporal variations in magnitude, as well as species-specific differences. Reference toxicant results for both the sea urchin and abalone tests indicate that this variability is real, not the result of variations in toxicity test performance. Such complexity presents a challenge for designing an appropriate monitoring program to study dry weather flow. A year-round sampling program consisting of multiple times, locations, and species is needed to provide accurate information.

What are the toxic components?—Limited progress was made towards answering the second question. Toxicity in most Ballona Creek samples was not due solely to the pH and salinity changes (Fig. 4), indicating the presence of toxic chemical components. The first (December 1992) Ballona Creek sample examined using phase I TIE procedures contained toxicants with characteristics similar to non-polar organics and oxidants, while toxicants in the second sample were similar to metal ions.

Hydrogen sulfide or ammonia are potential contributors to the toxicity in the Ashland storm drain samples. A sulfide odor was detected in some samples and hydrogen sulfide concentrations as low as 0.02 mg/L cause reduced sea urchin fertilization (SCCWRP 1994). Quantitative measurements of sulfide concentration were not made in this study. Ammonia concentration was elevated in samples from Ashland and has been identified in TIE studies with other effluent types as a cause of toxicity. None of the dry weather flow samples contained sufficient ammonia to cause toxicity at the test concentrations of $\leq 50\%$. The ammonia NOEC for red abalone embryos is 0.98 mg/L NH_3-N (unpublished data).

A previous study of southern California stormwater runoff used correlation techniques in an attempt to identify contaminants associated with toxicity (SCCWRP 1989). Suspended volatile solids was the only component exhibiting a significant negative correlation with toxicity. No meaningful relationships were identified between toxicity and concentrations of trace metals or chlorinated organics (e.g., DDT and PCB).

The type of toxicant in dry weather flow may vary with time and multiple chemicals may be present at toxic concentrations in a single sample. More extensive TIE work is needed to confirm these findings, investigate different sites, and provide more specific results.

TIE techniques, which rely upon chemical manipulations to inactivate and separate specific chemical groups, offer a better chance of success in identifying specific toxicants in storm drain samples than do techniques that rely solely on chemical analysis (Bailey et al. 1995).

Are ecological effects likely?—The Ballona Creek data indicate that dry weather flow is unlikely to produce direct adverse effects on water column organisms in Santa Monica Bay. Dry weather flow was diluted more than 100× before entering Santa Monica Bay and toxicity is not expected to be present in samples containing $<5\%$ effluent (20× dilution). Toxicity resulting from other (smaller) dry weather flow discharges into Santa Monica Bay is even less likely, since a smaller volume is discharged into a highly dispersive environment (surfzone).

Variations in receiving water toxicity among some samples from the mouth of Ballona Creek did not correspond to the concentration of dry weather flow present. This observation indicates the presence of an additional source of toxicity to the nearshore environment, possibly the adjacent Marina Del Rey.

Water column toxicity represents just one potential adverse effect resulting from dry weather flow. Other effects that might arise include sediment toxicity and increased contaminant bioaccumulation caused by the deposition of contaminated particles in dry weather flow. These factors were not addressed in the present study and must be investigated before a more complete evaluation of the biological effects of dry weather flow is possible.

Conclusions

- Dry weather flow samples from urbanized regions of Santa Monica Bay often contain unidentified chemicals at levels toxic to marine organisms.
- The composition and toxicity of dry weather flow is variable with time and between storm drains.
- The discharge of dry weather flow is unlikely to cause water column toxicity in Santa Monica Bay, but potential impacts on sediment quality, contaminant bioaccumulation by marine life, and human health have not been adequately studied.

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Adverse Effects of Hyposalinity from Stormwater Runoff on the Aggregating Anemone, *Anthopleura elegantissima,* in the Marine Intertidal Zone

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Abstract.—Coastal watersheds strongly impact the near-shore marine environment with freshwater inundation and runoff from the land. At Leo Carillo State Beach in Malibu, California, we have noticed marked effects of stormwater runoff on the local marine fauna. The aggregating sea anemone expels symbiotic algae under the influence of hyposaline stress, causing bleaching. The number and distribution of bleached sea anemones have increased dramatically from 1992 to 1995 at Leo Carillo State Beach under the influence of increased rainfall and the artificial broadening of the arroyo channel at its mouth.

On a gently sloping beach, many horizontal meters of marine habitat may be exposed to air during low tides. The area on rocks between the lowest low tide and the highest high tide, the rocky intertidal zone, is among the most productive habitats on earth, similar to a tropical rainforest or a coral reef (Leigh et al. 1987). Invertebrate animals living in the marine intertidal zone are hardy, generally well-adapted for the changing conditions of temperature, pH, oxygen, and carbon dioxide during tidal excursions (Truchot and Duhamel-Jouve 1980). However, because they are at the interface between the ocean and the land, they are more directly exposed to runoff than other marine organisms. If harmful conditions occur during low tides, any mitigating effects of dilution are not present and these organisms bear the full brunt of the exposure.

The intertidal sea anemone *Anthopleura elegantissima* normally maintains a symbiotic relationship with microscopic single-celled algae that live within its tissues. The dinoflagellate algae, or zooxanthellae, photosynthesize and provide a substantial fraction of the host anemone's nutritional needs (Fitt et al. 1982). Sea anemones have millions of zooxanthellae for each gram of tissue. *A. elegantissima* is very tolerant, surviving coverage by sand, exposure to air, and starvation for extended periods. However, when exposed to prolonged darkness, high temperatures, cold shock, or excessive time in bright sunlight, some sea anemones react by expelling some of their zooxanthellae (Muscatine et al. 1991). This expulsion causes a reduction in the green-brown color of the anemone and is therefore called bleaching. Bleaching by expulsion of zooxanthellae is seen in many species of reef-building corals, and is considered a sign of stress (Jokiel and Coles 1990). Without their symbionts, anemones and corals have much less energy available for growth and reproduction, and they may die. The presence or absence of symbiotic zooxanthellae provides a simple and fairly reliable indicator of health of these hardy and adaptable intertidal animals, although some of their color may

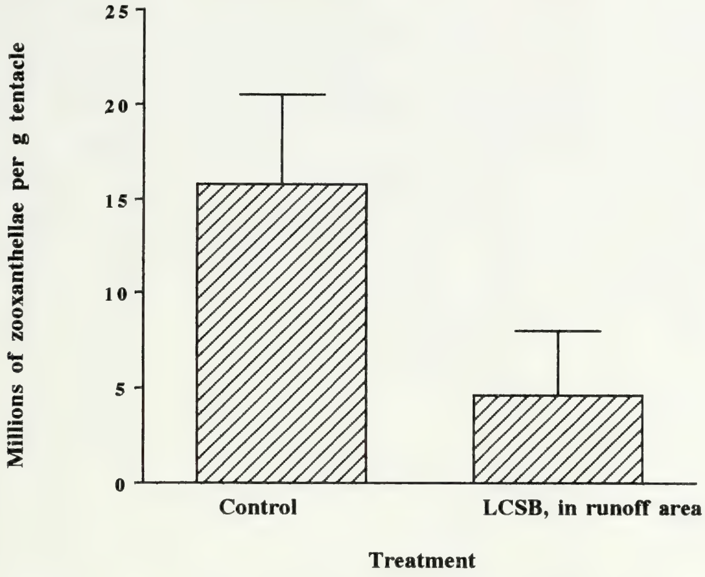

Fig. 1. Zooxanthellae were counted from tentacles of *A. elegantissima* from a control site and from the freshwater influx area of LCSB. The numbers of zooxanthellae per gram of tissue were significantly lower in the LCSB anemones. Shown are means ± standard errors.

come from endogenous pigments (Buchsbaum 1968). We suggest that they may be used as an indicator species for hyposalinity of seawater in rocky intertidal zone.

Leo Carillo State Beach (LCSB) in Los Angeles County, California, has extensive rocky substrate and a gently sloping face that provides an excellent potential habitat for rocky intertidal animals and plants. During the drought of the late 1980's, the intertidal fauna here was lush and diverse, and the area was frequented by members of the public, school classes, and park rangers for educational and interpretive lessons. However, following the heavy rains of 1991–1992, we observed a drastic decrease in the numbers and diversity of the intertidal organisms. Of those animals still remaining, the sessile *A. elegantissima* appeared much paler than before, indicating that bleaching had occurred (Engebretson and Martin 1994).

We did a series of laboratory experiments that indicated that the loss of color in *A. elegantissima* in the field was the result of loss of zooxanthellae (Engebretson and Martin 1994). Bleached anemones taken from LCSB had significantly reduced numbers of zooxanthellae (Fig. 1). We hypothesized that the bleaching was caused by excessive exposure to freshwater runoff. Healthy anemones from another site were placed into several different dilutions of seawater for time periods ranging from several days to several weeks. These *A. elegantissima* lost their symbiotic zooxanthellae and bleached rapidly, proportional to the strength and duration of the hyposaline exposure (Fig. 2). The anemones remained closed and did not feed while in hyposaline water.

A line transect to measure the number of bleached *A. elegantissima* at LCSB was done parallel to shore at a tidal height of −0.15 m over a distance of 120 m

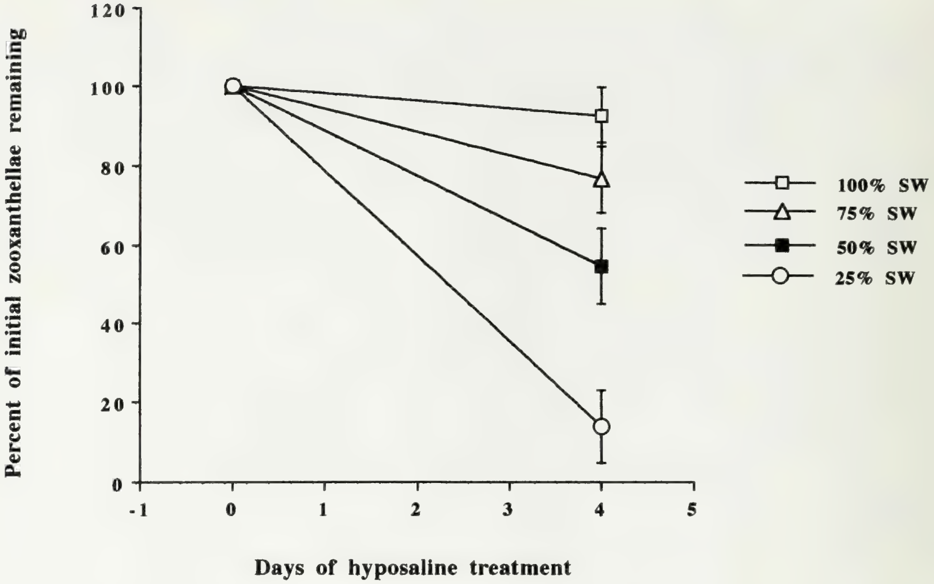

Fig. 2. *A. elegantissima* expelled zooxanthellae in response to constant exposure to hyposaline water, at the levels stated (100% = 32 ppt, 75% = 24 ppt, 50% = 16 ppt, and 25% = 8 ppt). After 4 days, all treatments except the control (100% SW) showed significant losses of zooxanthellae. Shown are means ± standard errors.

in 1992 (Engebretson and Martin 1994). At that time the anemones that were bleached were located within a limited area of freshwater runoff, resulting from discharge of the Arroyo Sequit (Fig. 3). Anemones located at the same tidal height but on either side of this freshwater runoff area were apparently not affected. We returned to this site in 1995 and ran line transects at four different tidal heights, −0.3 m, −0.24 m, −0.15 m, and −0.07 m, again parallel to shore over a distance of 132 m. These transect lines were separated by 3 m or more of horizontal distance. Line transects in 1995 indicated that anemones were bleached over a much greater area of the habitat, and at lower tidal heights, than in the previous transect (Fig. 4). We observed far less of the biological diversity that was so prevalent intertidally during the drought years in the intertidal zone at this site; all the sea urchins, snails, crabs, octopus, chitons, tidepool fish, and other marine organisms have apparently either died or moved into deeper water.

When anemones are exposed to short duration pulses of hyposaline water, similar to tidal exposure in tidepools during freshwater runoff, bleaching was even more pronounced and more rapid than bleaching in response to constant, long-term exposure to hyposaline conditions (Fig. 5). Thus, the field conditions of stormwater runoff during low tides over several days is potentially extremely detrimental and probably has caused the widespread bleaching of *A. elegantissima* seen in the transects at LCSB in 1995 (Lawson and Martin, unpublished), in addition to the profound loss of biodiversity in this habitat. Being sessile, *A. elegantissima* do not move away from harsh conditions. The hyposaline stress is likely to cause osmotic influx into cells and damage by rupture (Engebretson and Martin 1994; Gates et al. 1992).

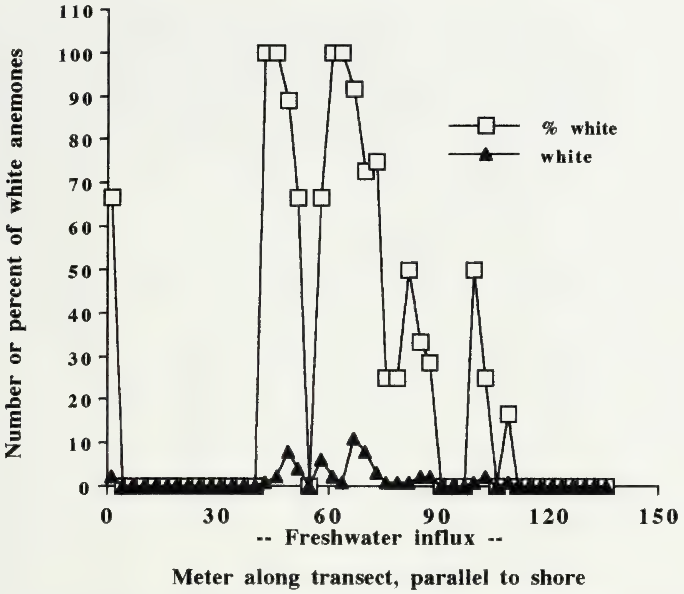

Fig. 3. Line transect data from 1992, showing bleaching within the freshwater influx area. Very little bleaching is shown outside of the channel for runoff. Transects were taken at −0.15 m tidal height.

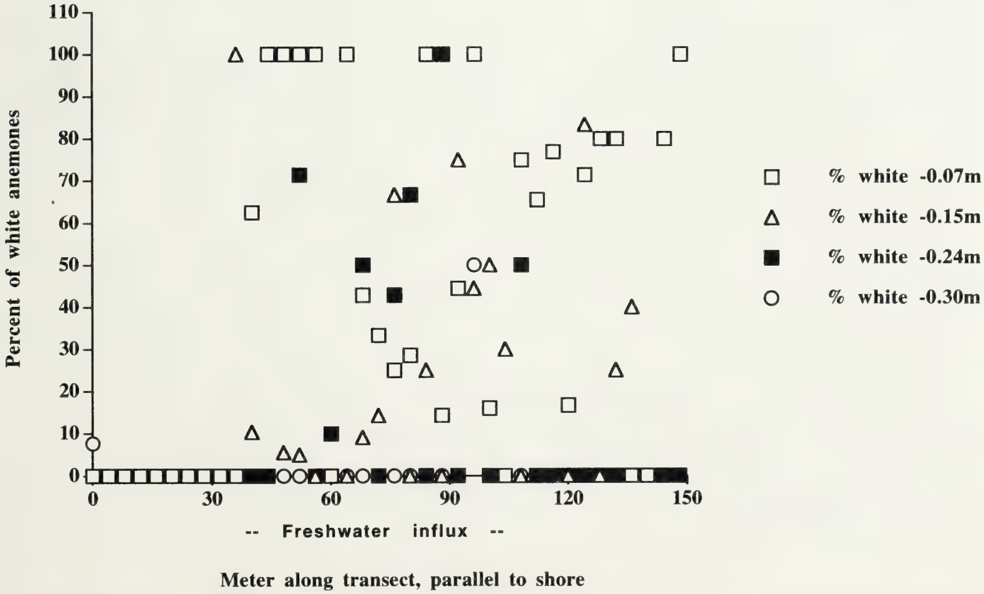

Fig. 4. Line transect data from 1995, showing increased influence of freshwater runoff over a larger area of the beach. Transects were taken at four tidal heights, −0.07 m, −0.15 m, −0.24 m, and −0.3 m.

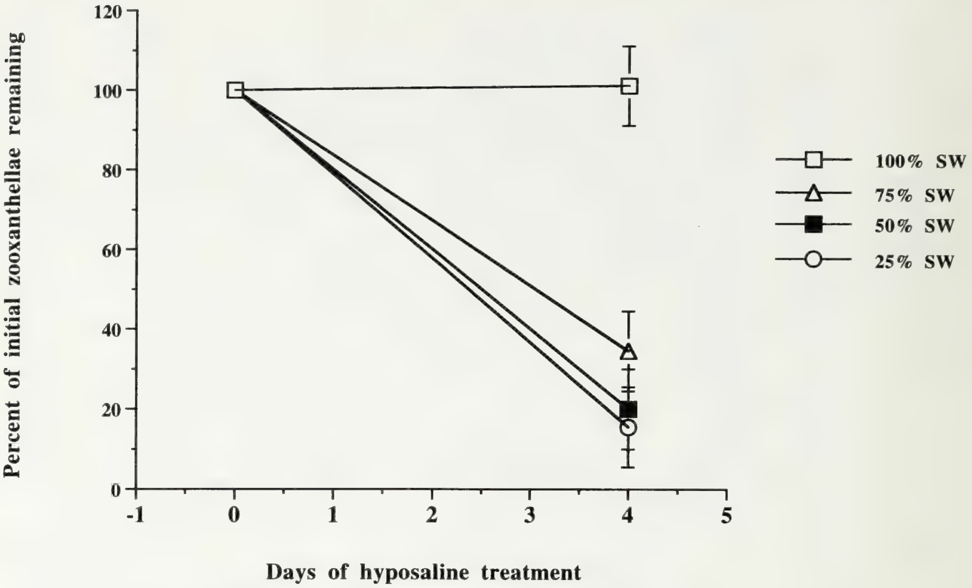

Fig. 5. Percent of initial numbers of zooxanthellae remaining following 4 days of treatments in which anemones were held in 100% seawater except for one 3 h pulse of hyposalinity per day (100% = 32 ppt, 75% = 24 ppt, 50% = 16 ppt, and 25% = 8 ppt). Shown are means ± standard errors.

Over the summer of 1995 we observed freshwater runoff from the arroyo on several occasions, covering a much greater area of the expanse of rocky intertidal habitat than the natural runoff channel. Heavy equipment had been used to bulldoze sand in order to direct the stormwater runoff much more broadly, rather than allowing it to continue to run in its natural, narrow channel. In addition, fresh water seeped farther across the beach by flow under the sand when the water was deep in the arroyo channel. From these studies it is not clear whether some other factors, such as pollutants, could also have contributed to the bleaching seen in the field. However, in the laboratory distilled water was used for all dilutions of artificial seawater in the experiments, and no contaminants were present. The hyposaline dilution alone is sufficient to cause the bleaching.

The increased area of LCSB containing bleached anemones in 1995 is cause for concern. Freshwater inundation is episodic but frequent at this site, and it is channeled artificially in a manner that causes direct effects in this near-shore marine environment. Particularly during low and minus tides, seawater dilution of stormwater runoff does not occur. We measured salinity in the field as low as 0 ppt, or freshwater, in the intertidal zone during a minus tide that occurred a few hours after a light rainfall. We are concerned that efforts to increase the speed and efficiency of stormwater runoff have taken precedence over efforts to preserve an important biological habitat that educates and is enjoyed by many people of the Los Angeles area.

Acknowledgments

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Yoder for valuable criticisms of the manuscript. This research was supported by a grant from the National Science Foundation Research Experience for Undergraduates program, BIR-9225034. Anemones were collected from Leo Carillo State Beach with permits issued by the California State Parks Service and from the control site with a permit from the California Department of Fish and Game (to KLMM).

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Abstract: Storm Water Pollution Regulatory Compliance in the Los Angeles Region Transportation Industry

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Pollutants in storm water discharges are an important source of surface water quality impairment in densely developed urban regions, and are targeted as one of the key sources of impaired water quality in Santa Monica Bay (SMBRP 1994). Stormwater pollutants are the target of multiple regulatory controls promulgated at the federal, state, regional, and local levels during the 1990s. The industrial sector conducts one set of urban activities where storm water pollutants originate, and is subject to a permit under the National Pollutant Discharge Elimination System of the U.S. Clean Water Act (U.S. EPA 1992). This research investigates the effectiveness of stormwater regulations in the Los Angeles region by facilities of one selected industrial segment, the transportation industry.

This abstract summarizes three presentations at the May 1995 Coastal Watershed Symposium in Fullerton, California, which include research that is more fully presented elsewhere. This research analyzed facilities of the transportation industry in the Los Angeles region to characterize their compliance to date with the 1992 California General Industrial Activities Storm Water Permit (the General Industrial Permit) (California State Water Resources Control Board 1992).

First, the researchers visited transportation facilities to develop an understanding of the kinds of industrial activities conducted, the potential sources of pollutants in storm water runoff that typically originate with those activities, and the forms of stormwater pollution control practices typically implemented by such facilities. The authors conducted site investigations at five facilities of the transportation industry within the Los Angeles region (Duke and Chung 1996). The five facilities were: a municipal bus maintenance facility; a small school bus maintenance yard; a municipal "corporate yard," operated to maintain and fuel municipal trucks, buses, and equipment; a small facility to maintain trucks for local and interstate hauling; and a large facility for maintenance, fueling, and loading of trucks for package shipping and delivery.

At these five facilities, the industrial activities where BMPs appear to have least successfully eliminated the possible stormwater pollutants fall into three categories: vehicle fueling; vehicle and equipment storage; and materials handling and storage. For these activities, the kind of BMPs that can be readily implemented at existing facilities without great financial burden do not appear to completely prevent discharge of pollutants in storm water runoff. Pollution control measures included covering activities with a roof, grading and berming to direct stromwater flow, spill prevention and control procedures, and dry clean-up procedures. Control measures identified are fully described elsewhere, but some general observations are possible. Some facilities had chosen to discontinue certain activities by contracting for services from offsite facilities. A large proportion of the storm water pollution prevention activities reported by these facilities are not new or specifically tailored for storm water regulatory compliance, but instead are originally designed to improve compliance with regulations addressing other fields such as hazardous waste, spill prevention, worker safety, and water use reduction. Relatively few new pollutant controls appear to have been implemented expressly for the purpose of compliance with new storm water regulations.

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Second, the researchers conducted a telephone survey addressed to all facilities of the selected industrial sector within a selected portion of the Los Angeles region, the Santa Monica Bay watershed (Duke and Beswick 1996). The purpose of this step was to estimate the proportion of facilities conducting business in this industry which also conduct industrial activities, and therefore are required to comply with the General Industrial Permit. Researchers developed a structured questionnaire, designed to determine whether a transportation-industry facility conducts industrial activities and therefore is required to comply with the General Industrial Permit. The questionnaire was administered by telephone to personnel of 48 facilities, a large proportion of the 68 facilities in the Santa Monica Bay watershed that appear in industrial directories with one or more SICs of the motor vehicle-related transportation industry (Dun and Bradstreet Corp. 1994; Database Publishing Co. 1994) and which are confirmed to be active as of November 1994. Responses were solicited equally from all 68 facilities, but 20 declined to participate.

One or more industrial activities were reported to be conducted at 56% of the facilities where a representative responded to the questionnaire (27 of 48 surveyed). Results show that industrial activities are conducted at a higher proportion of facilities in three trucking-related industries (4-digit SICs 4212, 4213, and 4214) than for other motor-vehicle transportation facilities (the eight other 4-digit SICs). Seventy-eight per cent of facilities in the trucking industry reported conducting industrial activities, compared to 43% of other motor-vehicle transportation facilities.

For the third segment of this research, the researchers reviewed files of the California Regional Water Quality Control Board, Los Angeles Region (RWQCB) to determine how many of those same facilities' operators have notified RWQCB of their intent to comply. The researchers searched for compliance documents filed by the same facilities identified as active in the Santa Monica Bay watershed. Facilities are required to file a Notice of Intent (NOI) with RWQCB if they conduct industrial activities, as the initial action signifying their compliance with the General Industrial Permit. Duke and Beswick (1996) include statistics for NOIs filed by the 48 facilities of the Santa Monica Bay population. Of the 27 facilities surveyed which conducted industrial activities, fewer than one-third (8 of 27) had filed the Notice of Intent to comply with the General Permit. The trucking industries again show different behavior: the compliance rate in this small sample of the trucking industry is zero per cent (none of the 14 identified trucking facilities required to comply had filed an NOI within 24 months after the due date), compared to 62% in facilities of all other transportation SICs, where 8 of 13 facilities determined to be required to comply had filed an NOI.

The researchers reviewed a representative sample of compliance documents submitted to RWQCB by facilities of the same industry segment, for the entire Los Angeles region, to characterize the continuing compliance efforts of regulated facilities. A total of 430 NOIs listing one or more motor-vehicle transportation SICs had been filed for facilities in the Los Angeles region as of December 31, 1994. Duke and Beswick (1996) summarize data from the annual reports and monitoring results submitted by a representative sample of 140 of those 430 facilities. Slightly more than half of the facilities in the sample (73 of 140 reviewed) submitted an annual report one year after filing the NOI; and just over one-third (53 of 140) submitted the required annual report two years after filing the NOI. Of 120 facilities in the sample required to submit monitoring results, 22% (27 of 120 facilities) submitted results for the first year required; and 31% (37 of 120) submitted results for the second year. These data do not fully describe facilities' compliance because the review does not include group monitoring reports, and facilities which applied to be part of a monitoring group may not have filed individual annual reports.

Acknowledgments

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ABSTRACTS

FIRST LINE DEFENSES AGAINST TOXINS. *D. Epel* and *B. Holland Toomey.* Hopkins Marine Station of Stanford University, Pacific Grove, CA 93950.

Estuarine organisms live in a chemical smorgasbord, where the sediments absorb and retain potentially toxic metabolites and defense molecules, as well as man-introduced toxins. What defense systems do these organisms possess? Are they unique to estuarine forms or do estuarine forms simply have a higher titer of a general detoxification mechanism? Most research on this question has focused on how the toxins are handled once they have entered the cell. We describe a novel mechanism in the echiuroid *Urechis caupo* and mollusk *Mytilus galloprovincialis,* which acts as a transport barrier to keep toxins out of the cell, so that the cell avoids the problem of ever having to modify the chemical to make it less toxic. The mechanism is the utilization of a non-specific transporter, the multixenobiotic transporter, which is a relative of the multidrug transport family and uses ATP to efflux a variety of moderately hydrophobic compounds out of the cell. Therefore, the toxins are only briefly in the cytoplasm where damage can occur. We consider the nature of this mechanism, its adaptive significance and evidence that it is involved in protecting estuarine forms.

EVALUATION OF CHARGED MICRO POROUS FILTERS FOR RECOVERY OF ENTEROVIRUSES FROM SEA WATER. *M. T. Yahya, C. E. Reed* and *C. D. McGee.* Environmental Science Laboratory, County Sanitation District of Orange County, Fountain Valley, CA 92728.

Positively charged filters have been recommended for the concentration of enteroviruses from groundwater and drinking water for higher virus recovery. Cellulose filters (1MDS) and cellulose/glass fiber filters (MK with graded density) were evaluated for recovery of poliovirus type 1 from seawater. As a comparison, electronegative virus adsorbent filters (epoxy fiberglass, Balston and Filterite filters with K27 as a prefilter) were tested. To determine the percent of the recovery of the seeded virus, cell associated poliovirus type 1 was added to 30 to 100 L of seawater for an initial concentration of 10^3 pfu/L. Viruses were eluted using 1.5 to 3% beef extract with glycine (pH 9.5 for MDS, MK and Filtrite, pH 7.0 for Balston), reconcentrated by organic flocculation, detoxified and tested for the formation of plaques on confluent monolayer of Buffalo Green Monkey kidney cells. Results indicate that with 1MDS filters, less numbers of poliovirus were recovered compared to the Balston or Filterite/K27 filter combination. Recovery ranged from 10 to 30 with 1MDS, 3.5 to 6.0% with Balston/K27, 1 to 10% with MK and 30 to 59% with Filtrite filters. Positively charged filters eliminated to need to condition the water the aluminum chloride and hydrochloric acid which may cause filter clogging during concentration.

EFFECTS OF COASTAL AND WATERSHED DEVELOPMENT ON SHORELINE POSITION AND SEDIMENTATION AT MUGU LAGOON, CALIFORNIA.

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Digital mapping of the mean high water shoreline and topographic profiles were used to monitor shoreline position and sediment volume at Mugu Lagoon from 1857–1989. The barrier was in dynamic equilibrium until 1901 when rates of shoreline migration increased. Dredging updrift at Port Hueneme in 1940 increased sand supply briefly, then formed a littoral barrier which initiated rapid net erosion on the Mugu barrier. Beach renourishment updrift of Mugu in 1961 reversed this trend, but since 1972 the shoreline segment updrift of the inlet has eroded more rapidly than at any time since 1857. This pattern is consistent with observations of more frequent westerly storms and storm wave hindcast modeling. Interior Mugu lagoon shorelines showed little net change until 1901, when the central and eastern lagoon began infilling at higher rates of net deposition. Infilling accelerated significantly during mid-century. The pattern and timing of infilling parallels landuse changes in the upland watershed. Between 1945 and 1990, agricultural acreage in the upland watershed was reduced by about one third, largely due to rapid expansion of urban and residential land cover. The U.S. Soil Conservation Service has documented measured increased sediment yield triggered by changing landuse in this watershed. Time series analysis of precipitation and stream hydrograph data show a sudden increase in total annual discharge on streams which deliver sediment to Mugu Lagoon beginning about 1970. Between 1945 and 1970, considerable interior shoreline change also resulted from military facility construction and maintenance, but since 1970 lagoon filling has primarily resulted from watershed-scale effects.

POST-FIRE SEDIMENT MOVEMENT IN MALIBU LAGOON WITH A POST-1995-FLOOD POST SCRIPT.

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Within six weeks of the Malibu fire of November 1–2, 1993, a 6 month pilot study was begun to monitor the effects of the expected sudden influx of sediment into Malibu Lagoon. Eight transects spaced 20 meters apart were established in the main lagoon with stations located every 20 meters along the transects. An additional 30 stations were located in the back bays. Five transects were established at approximately 100 meter spacings upstream of the lagoon on Malibu Creek. Elevation measurements were taken at weekly intervals in the main lagoon and back bays and bi-weekly on the creek.

Most of the stations in the back bays showed little change, although the most western back bay was very active within the first 100 meters closest to the ocean. The main channel in the lagoon also was more active than anticipated, often eroding vertically while adjacent areas were aggrading.

The model of levee development, in this case sub aqueous, is beautifully displayed, as well as general flood plane accretion and subsequent channel incision. Sediment storage occurred in part by oversteepening the main channel banks thereby facilitating removal by much lower flows.

AN ANALYSIS OF HISTORICAL PROFILE CHANGES IN THE ORANGE COUNTY COASTAL ZONE.

Ernesto A. Tabarez[1] and *Kwan M. Chan*[2]. [1]Department of Civil Engineering, California State University, Long Beach, CA 90840, [2]Department of Geology, California State University, Long Beach, CA 90840.

This study concentrates on the sedimentation processes along a 30 mile stretch south of the Long Beach Harbor. Analyses of data gathered by different local and federal agencies were utilized. The results should be helpful in determining long term effects of any contaminates in the sediment brought forth by sewage disposal and toxic waste spills. There were three types of data analyzed: bathymetric data, synoptic meteorological marine observation wave data, and research of current literature. The data was used to establish the effects of wave motion and sediment transport over a historical period. Based on the results, various sections of the coastal zone were characterized according to different degrees of stability or instability. From onshore to as far as 9000 ft. from the benchmarks, the numerical analyses of the data provided a detailed picture of the historical changes. (Primary source of information from U.S. Army Corps of Engineers, Los Angeles District and Orange County Department of Beaches and Harbors.)

REDUCING NATURAL ROUGHNESS: FIRST SAN DIEGO RIVER IMPROVEMENT PROJECT, SAN DIEGO, SAN DIEGO COUNTY, CALIFORNIA.

Pablo O. Grabiel. University of California, Los Angeles, CA 90024 and California State University, Fullerton.

Rivers flowing through urban areas pose a variety of hazards to the community. These hazards need to be addressed by municipal leaders and planners. Storm floods, vector control, dangers inherent by the attractive nuisance posed by a river all must be considered by government authorities. Concomitantly, the measures intended to alleviate such hazards posed by a riparian system tend to negatively impact the sensitive riparian environment itself. The reduction of natural roughness at the riparian-terrestrial habitat boundary is one such consequence. The First San Diego River Improvement Project attempts many objectives: maintaining a thriving riparian ecosystem, providing for recreation, and sustaining natural riparian functions. This project's impact is studied over time to assess the consequences of these changes upon the river's natural environment.

NITROGEN ADDITIONS TO ESTUARIES FROM COASTAL WATERSHEDS: HOW CAN SCIENTISTS AND MANAGERS DEAL WITH UNCERTAIN INFORMATION?

G. Collins and *J. N. Kremer.* University of Southern California, CA 90089.

After a four-year study of the impacts of watershed development on estuaries (the Waquoit Bay Land-Margin Ecosystem Research Project, Cape Cod, MA), there are still gaps in our understanding of how nitrogen travels from watersheds to coastal waters. Because of these gaps, predictions of anthropogenic nutrient loading rates from watersheds are uncertain, as are predictions of responses of coastal ecosystems to these nutrients. This uncertainty presents problems to scientists trying to understand how nutrient loading forces changes in coastal ecosystems, and to planners trying to prevent or remediate such changes by managing watershed development. We have quantified uncertainty in calculations of nitrogen loading for Waquoit Bay (the standard deviation is about 40% of the loading rate), and have identified two parts of the loading calculation that contribute the most to that uncertainty: denitrification in groundwater during travel to the sea, and the efficiency with which septic systems remove nitrogen from sewage. Further investigations of these processes are necessary to increase the certainty in loading calculations. Managers, however, cannot wait for this information, and so must make decisions about development in the coastal zone with uncertain information. Uncertainty estimates may be used to help make conservative decision and assess "worst case scenarios," but it may be necessary to turn to other criteria (economic, aesthetic, etc.) in the management process.

FATE OF FERTILIZER-DERIVED NITROGEN ENTERING A SALT MARSH IN GROUND WATER: CLUES FROM STABLE NITROGEN ISOTOPE RATIO ANALYSIS.

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To investigate the fate of anthropogenic nitrogen in ground water within a salt marsh ecotone and the effects of ground water inputs on marsh vegetation, I measured the natural abundance of ^{15}N in pore water NO_3–N and NH_4–N, and in the salt marsh halophyte, *Salicornia virginica,* along an environmental gradient from agricultural land into a salt marsh. The increase in $\delta^{15}NNO_3$ ($\sim +40‰$), accompanied by the decrease in NO_3–N (and total dissolved inorganic N, DIN) concentration along the gradient, suggested that the salt marsh ecotone is a site of transformation, most likely through denitrification, of inorganic nitrogen in ground water. *S. virginica* (and the parasitic herb, *Cuscuta salina*), were enriched in ^{15}N along the tidal marsh boundary ($\delta^{15}N = \sim 16‰$), relative to high and middle marsh locations ($\delta^{15}N = \sim 8‰$), indicating that ground water nitrogen is also retained as vegetative biomass. Ground water inputs enhanced the standing crop, above ground productivity, and nitrogen content of *S. virginica* but the relative effects of pore water salinity and DIN concentration on these parameters were not determined. ^{15}N enrichment of marsh plants by ground water DIN inputs could prove useful in tracing these inputs in the marsh.

INSTRUCTIONS FOR AUTHORS

The BULLETIN is published three times each year (April, August, and December) and includes articles in English in any field of science with **an emphasis on the southern California area.** Manuscripts submitted for publication should contain results of original research, embrace sound principles of scientific investigation, and present data in a clear and concise manner. The current AIBS *Style Manual for Biological Journals* is recommended as a guide for contributors. Consult also recent issues of the BULLETIN.

MANUSCRIPT PREPARATION

The author should submit *at least two additional copies with the original,* on 8½ × 11 opaque, nonerasable paper, double spacing the entire manuscript. ***Do not break words at right-hand margin anywhere in the manuscript.*** Footnotes should be avoided. **Manuscripts which do not conform to the style of the BULLETIN will be returned to the author.**

An abstract summarizing in concise terms the methods, findings, and implications discussed in the paper *must* accompany a *feature article. Abstract should not exceed 100 words.*

A feature article comprises approximately five to thirty typewritten pages. Papers should usually be divided into the following sections: abstract, introduction, methods, results, discussion and conclusions, acknowledgments, literature cited, tables, figure legend page, and figures. Avoid using more than two levels of subheadings.

A research note is usually one to six typewritten pages and rarely utilizes subheadings. Consult a recent issue of the BULLETIN for the format of *notes.* Abstracts are not used for notes.

Abbreviations: Use of abbreviations and symbols can be determined by inspection of a recent issue of the BULLETIN. **Omit periods after standard abbreviations:** 1.2 mm, 2 km, 30 cm, but Figs. 1–2. Use numerals *before* units of measurements: 5 ml, but nine spines (10 or numbers above, such as 13 spines). The metric system of weights and measurements should be used wherever possible.

Taxonomic procedures: Authors are advised to adhere to the taxonomic procedures as outlined in the International Code of Botanical Nomenclature (Lawjouw et al. 1956), the International Code of Nomenclature of Bacteria and Viruses (Buchanan et al. 1958), and the International Code of Zoological Nomenclature (Ride et al. 1985). Special attention should be given to the description of new taxa, designation of holotype, etc. Reference to new taxa in titles and abstracts should be avoided.

The literature cited: Entries for books and articles should take these forms.

McWilliams, K. L. 1970. Insect mimicry. Academic Press, vii + 326 pp.

Holmes, T. Jr., and S. Speak. 1971. Reproductive biology of *Myotis lucifugus.* J. Mamm., 54:452–458.

Brattstrom, B. H. 1969. The Condor in California. Pp. 369–382 *in* Vertebrates of California. (S. E. Payne, ed.), Univ. California Press, xii + 635 pp.

Tables should not repeat data in figures *(line drawings, graphs, or black and white photographs) or contained in the text.* The author must provide numbers and short legends for tables and figures and place reference to each of them in the text. Each table with legend must be on a separate sheet of paper. All figure legends should be placed together on a separate sheet. **Illustrations and lettering thereon should be of sufficient size and clarity to permit reduction to standard page size;** *ordinarily they* **should not exceed 8½ by 11 inches** in size and after final reduction lettering must equal or exceed the size of the typeset. All half-tone illustrations will have light screen (grey) backgrounds. Special handling such as dropout half-tones, special screens, etc., must be requested by and will be charged to authors. **As changes may be required after review, the authors should retain the original figures in their files until acceptance of the manuscript for publication.**

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A cover illustration pertaining to an article in the issue or one of general scientific interest will be printed on the cover of each issue. Such illustrations along with a brief caption should be sent to the Editor for review.

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COVER: Bleached specimen of Aggregating Anemone, *Anthopleura elegantissima* at Leo Carillo State Beach. Photo by K. Martin.

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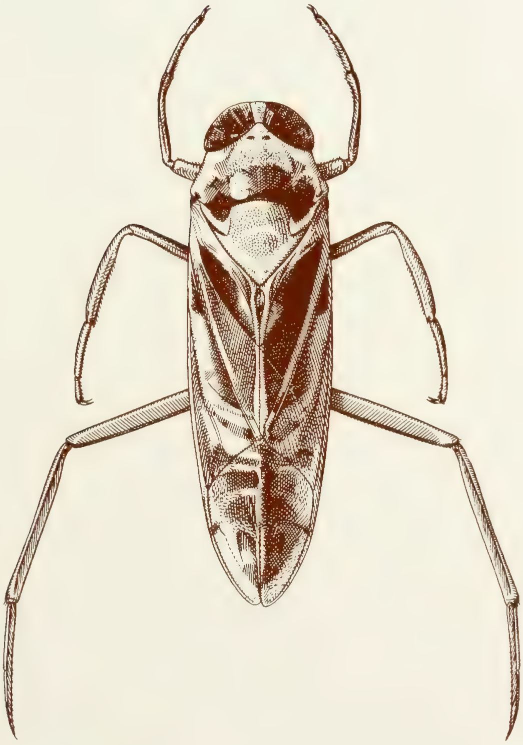

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The Status and Distribution of the Notonectidae (Heteroptera: Hemiptera) of the Baja California Peninsula, Mexico

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Abstract.—The notonectid fauna of the Baja California peninsula is composed of two genera, *Notonecta* represented by six species (*hoffmani, kirbyi, shooterii, unifasciata, indica, melaena*) and *Buenoa* by seven species (*arizonis, omani, margaritacea, scimitra, albida, thomasi, platycnemis*). With six exceptions, all collection sites (approx. 100) for the 13 species are recorded here for the first time. Distribution maps, discussion of the zoogeography of the notonectids on the Baja California peninsula, and hypotheses as to their origins and affinities are included. A key is provided to facilitate the identification of the 13 species.

The Baja California peninsula is geographically oriented in an essentially north-south direction, although it extends from the U.S./MEXICO border in a south-easterly direction. It is approximately 1290 kilometers in length and varies in width from 48 to 232 kilometers. This geographically isolated area is divided politically at the 28th parallel into the northern state of Baja California and a southern state, Baja California Sur.

Lower California occupies an area that is of particular interest to biogeographers and students of biodiversity in that within its boundaries is the transition between two major faunistic zones, a northern temperate (Nearctic) and a southern tropical (Neotropical) (Brown and Opler 1990). Complicating traditional distribution patterns, peninsulas are intermediate between island and continental land masses, and dispersal patterns usually are altered in such a way that migration, colonization and extinction patterns differ from those of islands or continents (Due and Polis 1986).

Although the dominant land mass is low-lying desert, this topography is broken by four major mountain ranges. The two most northerly, the Sierra de Juárez and the Sierra San Pedro Mártir, are in essence a continuation of southern California ranges. The other two conspicuous ranges, the Sierra de la Giganta and the Sierra de la Laguna, occur in the southern third of the peninsula.

The topography of northern Lower California is similar to that of adjacent southern California. The central two-thirds is true desert, characterized by barren mountains and sandy plains. The southern region lies within the tropics and is dominated by the Sierra de la Laguna.

The Notonectidae are a characteristic feature of aquatic insect life in almost all parts of the World. However, they are practically non-existent in the literature and collections relative to the entomofauna of the Baja California peninsula. Only two authors have published locality records for this family in Lower California. Uhler (1894) cites three species of *Notonecta* and two species of *Buenoa* from four sites, and Hungerford (1933) records two species of *Notonecta* from four sites (including two Uhler citations). Two authors (McPherson 1966; Thomas 1939) have published articles that contain information of a general nature that relates to the distribution of *Notonecta* on the Baja California peninsula but do not cite locality records. McPherson quotes Hungerford (1925) in stating that *Notonecta hoffmani* occurs in southern California, Arizona, and Baja California, Mexico. Thomas, in discussing the distribution of *Notonecta* species "groups" (primarily on mainland Mexico), cites the regional presence of the *shooterii* and *mexicana* "groups" on the peninsula but does not provide precise species or localities. The logical assumption for this gap in our knowledge is a lack of sufficient field study and/or the rarity of members of this family on this isolated peninsula. The intent of this paper is to document for the first time, the taxa currently present in Lower California and their distribution patterns, and to provide hypotheses relative to their origins and affinities.

Methods

Due to the fact that "ESTADO DE BAJA CALIFORNIA" is the official designation for the northern state of the peninsula, I think it is useful to point out that when I refer to the peninsula as a whole in the text, the terms "Baja California Peninsula" and "Lower California" are used interchangably in order to eliminate any confusion relative to the more common (but technically incorrect) usage of the term "Baja California" (Snelling 1987).

Members of the family Notonectidae occur in a variety of habitats but prefer the quiet waters of ponds and small intermittent streams. Although a number of species may occur sympatrically, each tends to seek its own niche. The vast majority of the Baja California peninsula is classified as low-lying desert with a "backbone" comprised of a series of mountain ranges. During the present study an effort was made to investigate the diverse habitats from spring-fed oases of the Central Desert (Fig. 1) to the well-watered canyon streams in the mountain ranges (Fig. 2).

The entire length of the peninsula was visited during this study (1987–1994). Adult specimens have been vouchered for every month of the year. Searching isolated sites reachable by poor backcounty roads and trails were key to the success of the field work. When fish (both native and introduced) were encountered in these recruitment-limited sites, notonectids were seldom encountered. In the overwhelmingly arid environment of the peninsula, it was important to learn the identifying features of the terrain that generally indicated the presence of freshwater. Presence of hydrophytic vegetation (e.g., palm trees and willows) and areas surrounding old mission sites proved particularly productive. Of course, the many spring-fed intermittent streams in the mountain and foothill canyons proved fruitful. Man-made water-holding structures such as livestock tanks, small dirt and concrete dams, and interesting to note, swimming pools were productive sites for these freshwater insects. The always gracious and friendly ranchers and others that we encountered along the way were of immeasurable help in permitting us to search their livestock tanks, and many identified other local sources of freshwater where they had observed "*insectos chiquitos.*" Also, Allen and Murvosh (1983) published useful information on the location of streams on the Baja California peninsula that proved helpful to us in locating notonectid sites.

In the species accounts that follow, the collecting sites for the species of each

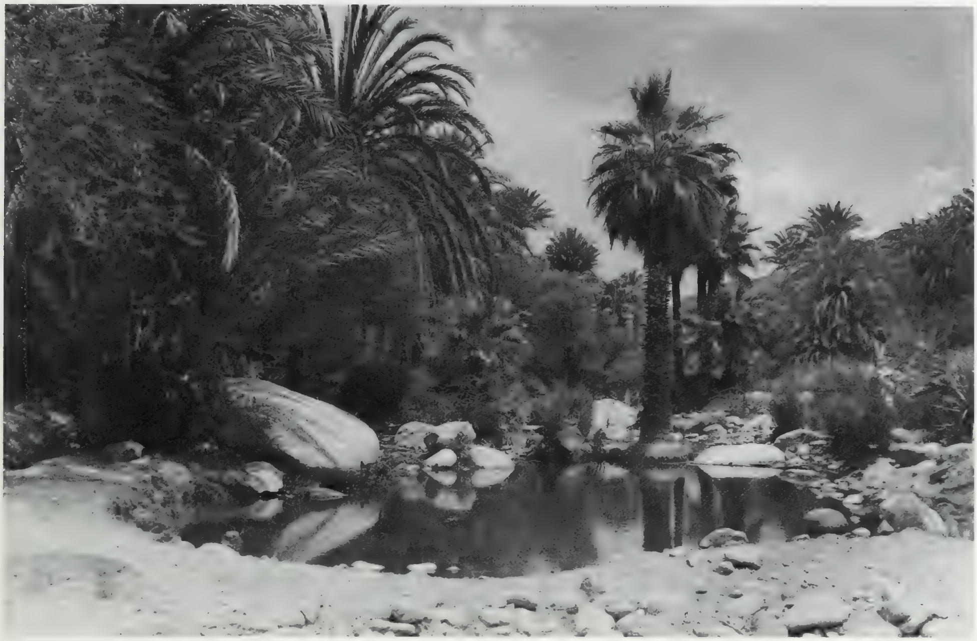

Fig. 1. Oasis, Santa Gertrudis Mission site.

genus are recorded from north to south for each of the two peninsular states. Since many sites are both isolated and ephemeral in nature, and duplication in village names from one region to another is common, it seems prudent to provide geographic coordinates for each locality (Appendix). These were determined by consulting the "BAJA Topographic Atlas Directory" published by Topography International, Inc., San Clemente, California. Photographs and maps were prepared by the author. Abbreviations for institutions cited in the text are as follows: California Academy of Sciences (CAS); California State University, Long Beach (LBSU); San Diego Museum of Natural History (SDM); California State University, San Diego (SDSU); University of Kansas (KU); University of Arizona (UA). Specimens without attribution are deposited in the Natural History Museum of Los Angeles County (LACM).

Results

The notonectid fauna of Lower California is comprised of two genera, *Notonecta* Linnaeus and *Buenoa* Kirkaldy. *Notonecta* is represented by six species; *hoffmani* Hungerford, *kirbyi* Hungerford, *shooterii* Uhler, *unifasciata* Guérin-Méneville, *indica* Linnaeus, and *melaena* Kirkaldy. *Notonecta kirbyi* and *unifasciata* are recorded for the first time from the peninsula. *Buenoa* is represented by seven species; *margaritacea* Torre-Bueno, *scimitra* Bare, *arizonis* Bare, *omani* Truxal, *thomasi* Truxal, *albida* (Champion), and *platycnemis* (Fieber). All *Buenoa* except *arizonis* and *platycnemis* are recorded for the first time from the peninsula. As noted in the species accounts that follow, the northern state, Baja California, has five of the six species of *Notonecta* and four of the seven species of *Buenoa*. The southern state, Baja California Sur, has three of the six species of *Notonecta*

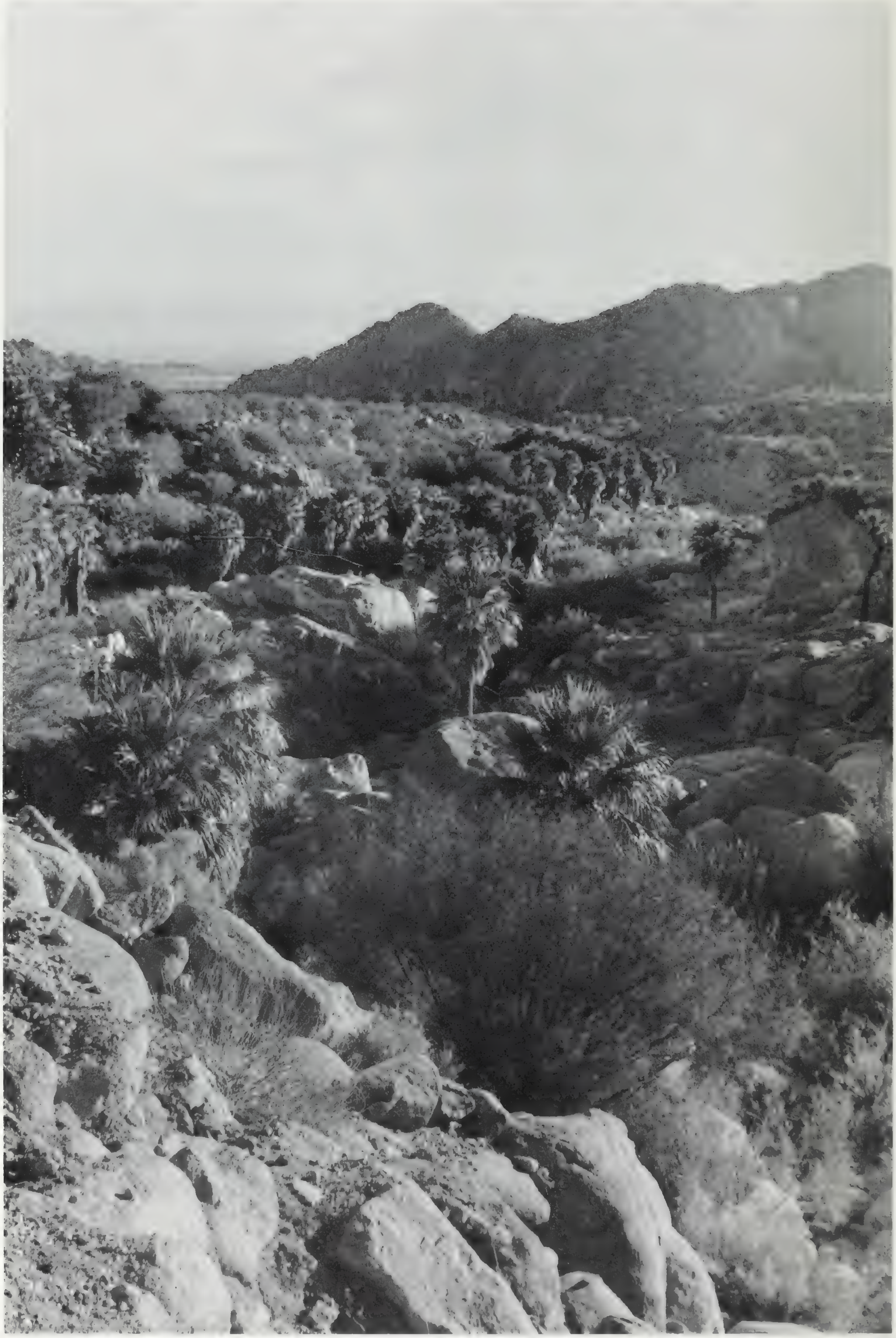

Fig. 2. Guadalupe Canyon, eastern slope of Sierra de Juárez.

and six of the seven species of *Buenoa.* All of the approximately 100 locality records cited below are new for Lower California except for six that were cited by Uhler (1894) and Hungerford (1933). Specimens are deposited in the collections of the Instituto de Biología, Universidad Nacional Autonoma de Mexico, Mexico, D.F., with duplicates in the Natural History Museum of Los Angeles County, Los Angeles, California, except where otherwise indicated in parentheses following the collectors names.

Species Accounts

The two genera of Notonectidae found on the Baja California peninsula are easily distinguished. In general body form, *Buenoa* (Fig. 3) are long and slender compared to the larger, more robust *Notonecta* (Fig. 4). Species of the genus *Buenoa* are readily distinguished from *Notonecta* in possessing an elliptical pit at the anterior end of the hemelytral commissure, asymmetrical parameres on the male genital capsules, stridulatory structures on the third rostral segment and front tibia of the male, and antennae three-segmented rather than four-segmented as in *Notonecta.*

Key to *Notonecta* of Lower California

1. Keel of 4th abdominal sternum bare except at sides 2
   Keel of 4th abdominal sternum pilose 3
2. Smaller species, no larger than 10 mm in length (♂) to 11.5 mm (♀); head broad, ⅚ as wide as pronotum .... *hoffmani* Hungerford
   Larger species, at least 13.8 mm in length (♂) to 15.5 mm (♀); head narrower, ⅔ as wide as pronotum .... *kirbyi* Hungerford
3. Trochanter of middle leg angulate at inner posterior angle .... *unifasciata* Guérin-Méneville
   Trochanter of middle leg rounded at inner posterior angle 4
4. Pronotum equal to or shorter than scutellum; not distinctly robust .... *indica* Linnaeus
   Pronotum longer than scutellum; robust in body form 5
5. Large and robust; anterior margin of head distinctly convex and approximately ½ length of pronotum .... *shooterii* Uhler
   Smaller and less robust; anterior margin of head flattened and approximately ⅓ length of pronotum .... *melaena* Kirkaldy

Genus *Notonecta* Linnaeus 1758

This is a ubiquitous genus with a world-wide distribution. It contains about 70 species, approximately 47 of which have been recorded from the Western Hemisphere. Six species are here recorded for the Baja California peninsula (Figs. 5, 6).

Notonecta hoffmani Hungerford 1925

This species was first described from a series taken at Laguna Beach, California. Published records cite it from central and southern California, southern Arizona, and Lower California, Mexico, but not from the Mexican mainland.

It is a species of moderate size, with length 10–11.5 mm and width 3.9–4.5 mm. General facies are red-orange with a black scutellum and brown-black he-

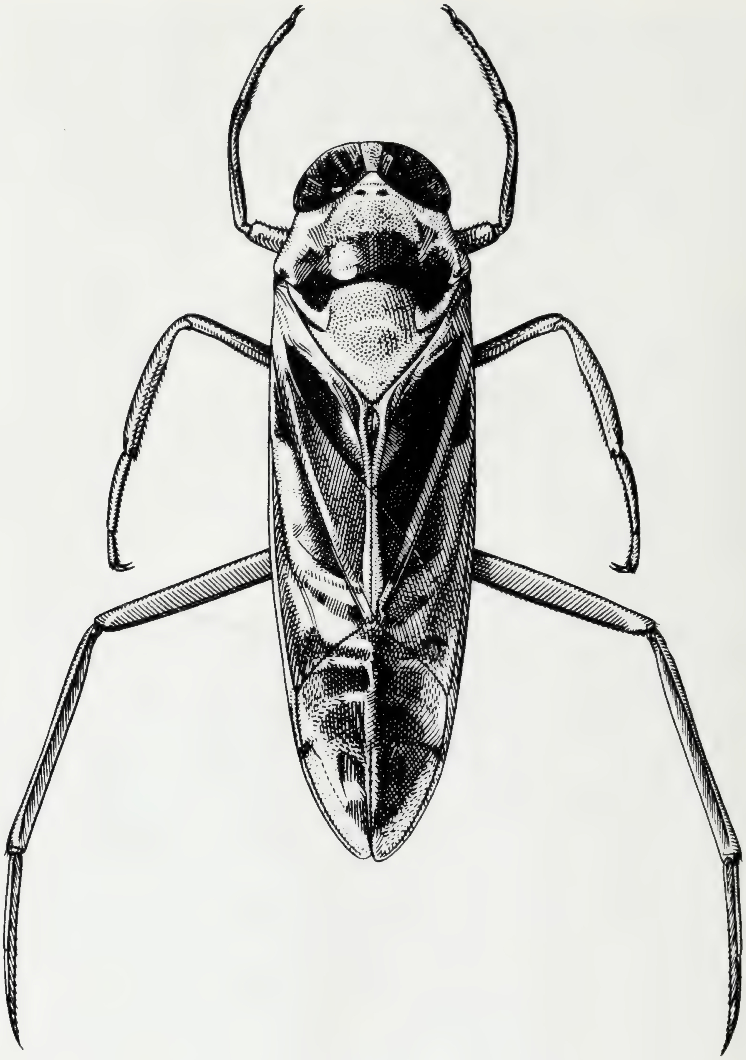

Fig. 3. *Buenoa scimitra,* male, dorsal view (from Usinger, 1956).

melytral membrane. As diagnosed by Hungerford (1933), this species is a member of the *N. mexicana* Amyot & Serville complex which currently is composed of approximately six similar species. No other member of the complex is recorded for the Baja California peninsula. *Notonecta hoffmani* is found throughout the peninsula but is most abundant in Baja California Sur.

Distribution.—BAJA CALIFORNIA: El Tajo Canyon, 9-IX-1957, J. Roberds & 18-IX-1953, 21-IV-1951, C. Harbison (SDM); 2.7 mi SW Ejido Ignacio Zaragosa, Hwy 3, 13-VIII-1993, F. Truxal; Guadalupe Canyon, 22-II-1959, E. Sleeper (LBSU) & 2-3-V-1964, R. Snelling, & 5-X-1988, F. Truxal; 10 mi E Ojos Negros, 11-VI-1990, F. Truxal; 2 mi E Ojos Negros, 6-IV-1961, F. Truxal; 34 mi SE Ensenada, 6-V-1987, F. Truxal; 66 mi SE Ensenada, 24-III-1960, 30-I-1968, E.

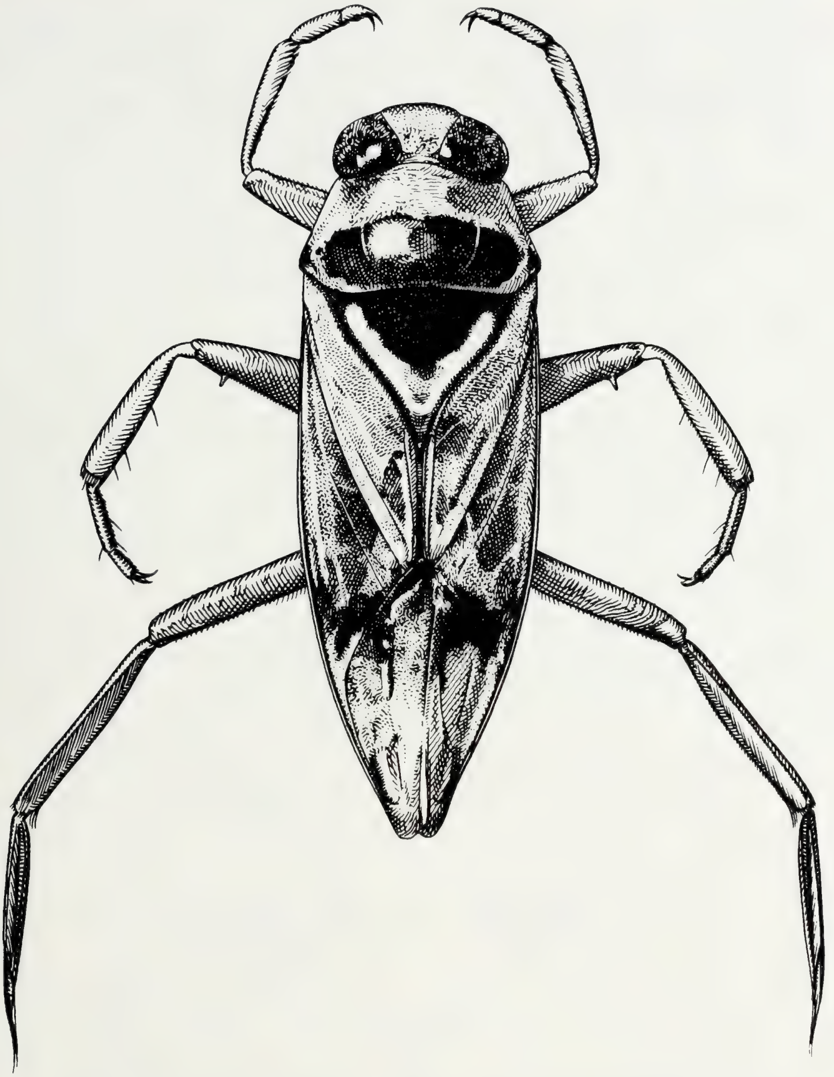

Fig. 4. *Notonecta unifasciata,* male, dorsal view (from Usinger, 1956).

Sleeper (LBSU); El Mayor, 4 mi NE Ensenada, 22-I-1981, J. Brown & D. Faulkner (SDM); 3 mi S La Zapopita, Valle de Trinidad, 10-IV-1961, F. Truxal; 20 mi S Santo Tomás, 3-VIII-1938, A. Michelbacher & E. Ross (CAS); 1 mi W San Matías Pass, 7-VI-1961, E. Sleeper (LBSU); Meling Ranch (San José), 11-X-1988, F. Truxal; Canyon del Cabane (Cañada el Novillo), 26-I-1967, E. Sleeper (LBSU); San Fernando Mission, 40 mi S El Rosario, 27-IV-1992, F. Truxal; 6 mi SW El Mármol, 12-IX-1989, F. Truxal; 20 mi N Punta Prieta, 21-IV-1962, C. Harbison (SDM); Mission San Borja, 9-VI-1990, F. Truxal. BAJA CALIFORNIA SUR: Santa Agueda, 8-X-1988, F. Truxal; 9 mi W Hwy 1 on San Isidro Rd., 11-XI-1991, F. Truxal; 10.5 mi W Hwy 1 on San Isidro Rd., 9-X-1988, F. Truxal; 11 mi E San Javiér, 12-V-1987, F. Truxal; 2.5 mi E Las Parras, 28-II-1969, K.

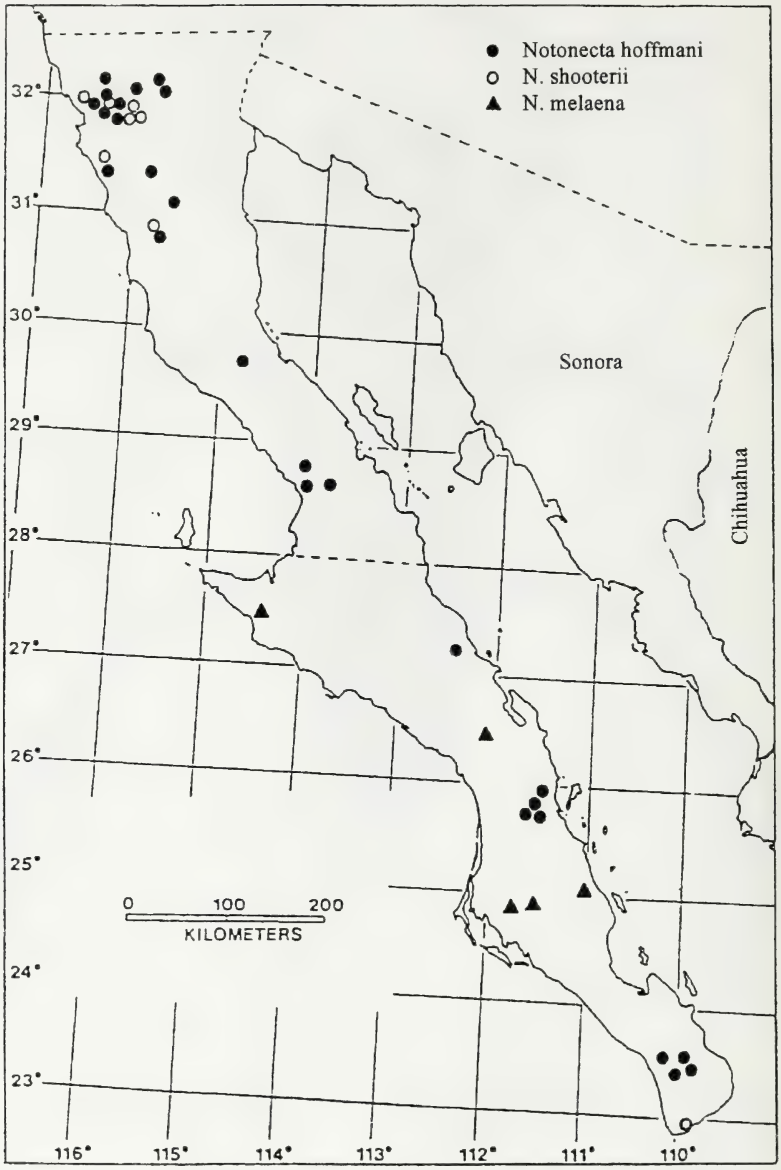

Fig. 5. Distribution of *Notonecta* in Lower California. Closed circles *N. hoffmani,* open circles *N. shooterii,* closed triangles *N. melaena.*

Stager; Las Parras, 11-XI-1991, F. Truxal; La Laguna (5500'), 21-III-1965, A. Sloan (SDM) & 20-23-X-1968, E. Sleeper & F. Moore (LBSU); 3 mi E La Burrera, 17-19-X-1968, E. Sleeper & F. Moore (LBSU); Boca de la Sierra (900'), 5-6-III-1969, R. Snelling; 5 km NW Miraflores, 11-XI-1979, G. Challet (LBSU).

Records from the literature.—BAJA CALIFORNIA: El Paraiso, May, 1889, C. D. Haines (Uhler 1894, Hungerford 1933); Santa María, May 1889, C. D. Haines (Hungerford 1933).

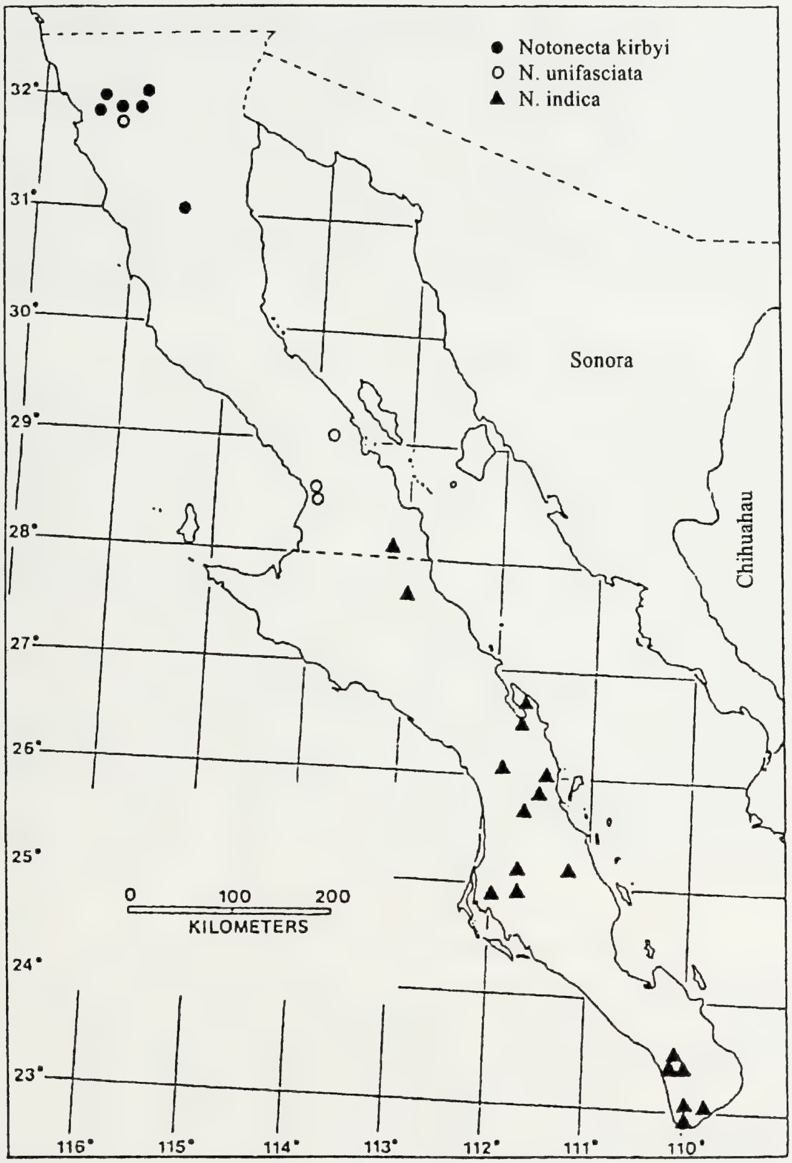

Fig. 6. Distribution of *Notonecta* in Lower California. Closed circles *N. kirbyi,* open circles *N. unifasciata,* closed triangles *N. indica.*

Notonecta kirbyi Hungerford 1925

This species was first described from a series taken in Emery County, Utah. Published records cite it from western United States and western Canada. *Notonecta kirbyi* previously has not been recorded from Lower California or from the mainland of Mexico.

This is the largest representative of the family Notonectidae in Lower California, an elongate species measuring 13.8–15.5 mm in length and 4.5–4.8 mm in width. General facies are typically tan and black or red and black, with clavus and basal half of corium tan, orange or red mottled with black. On the Baja California peninsula, this species was found at only seven sites, all in the Sierra de Juárez and Sierra San Pedro Mártir in the state of Baja California.

Distribution.—BAJA CALIFORNIA: El Tajo Canyon, 16-IX-1953, C. Harbison (SDM); 2.2 mi SE El Topo, 25-III-1970, J. Gruwell & P. Perkins (LBSU); 3.6 mi SE El Rayo, 1-2-VII-1960, E. Sleeper (LBSU); 2 mi E El Progreso, 22-23-III-1970, J. Gruwell & P. Perkins (LBSU); 66 mi SE Ensenada 30-I-1968, E. Sleeper (LBSU); Vallecitos, San Pedro Mártir Nat. Prk., 13-IX-1989 & 12-VII-1993, F. Truxal; San Pedro Mártir Nat. Prk. Hdqts., 30-VI-1992, K. Stager.

Notonecta shooterii Uhler 1894

This species was first described from a series taken near San Diego, California. Published records cite it from Coos County, Oregon south through California and into Lower California but not from mainland Mexico. The present study records it from seven localities in the northern state of Baja California and, from the literature, a single specimen taken by Gustav Eisen at San José del Cabo in the southern state of Baja California Sur (Uhler 1894).

It is a robust species measuring 11.7–13.5 mm in length and 4.4–4.8 mm in width. It is bichromatic with one form pale luteous and the other, dark brown to black with pale luteous streaks and spots on the hemelytra.

Distribution.—BAJA CALIFORNIA: Laguna Hanson, 7-VII-1960, E. Sleeper (LBSU); 3.6 mi SE El Rayo, 1-2-VII-1960, E. Sleeper (LBSU); 25 mi E Ojos Negros, 6-IV-1961, F. Truxal; 66 mi SE Ensenada, 30-I-1968, E. Sleeper (LBSU); Ensenada, 27-VI-1925, W. Wright (SDM); Arroyo Santo Tomás, 4-VII-1958, E. Sleeper (LBSU); Meling Ranch (San José), 11-X-1988, F. Truxal.

Records from the literature.—BAJA CALIFORNIA SUR: San José del Cabo, date unknown, Gustav Eisen (Uhler 1894).

Notonecta indica Linnaeus 1771

This is the only species of *Notonecta* from Lower California that occurs in both North and South America. Published records cite it from southern United States (south of 37°N latitude), mainland Mexico, through Central America to Colombia, South America and the West Indies. The records cited below are the first for the Baja California peninsula since a record published by Uhler (1894) but misidentified as *N. undulata* Say (Hungerford 1933).

It is a medium-sized species measuring 10–11 mm in length and 3.36–3.75 mm in width. General facies are typically black and white with a broad black band across the hemelytra. However, this species varies greatly in color, from white to nearly black.

Distribution.—BAJA CALIFORNIA: Bahía de Los Angeles, 17-IV-1940, C. Harbison (SDM); Mission Santa Gertrudis, SE El Arco, 7-VIII-1994, F. Truxal. BAJA CALIFORNIA SUR: San Ignacio, 8-VI-1990, F. Truxal; El Salto, E shore Bahía Concepción, 10-XI-1991, F. Truxal; south shore Bahía Concepcíon (stock tank), 10-XI-1991, F. Truxal; 2 mi E Canipolé, 12-XI-1968, E. Sleeper & F. Moore (LBSU); 14 mi N Loreto, 18-IX-1983, R. Snelling; Comondú, 19-XI-1956, C. Harbison (SDM); 1 mi SW Palo Blanco, 8-9-XI-1968, E. Sleeper & F. Moore (LBSU); Ciudad Constitución (swim. pool), 11-XI-1991, F. Truxal; Rcho El Huatamote, 13 mi W Primera Agua, 25-VI-1994, F. Truxal; 7 mi NE Las Pocitas, 25-VI-1994, F. Truxal; Presa Santa Inés, 5.2 mi N Todos Santos, 13-XI-1991, F. Truxal; Rcho Halada, 5 mi SE Todos Santos, 9-IX-1989, F. Truxal; San José del Cabo (Laguna), 23-VI-1994, F. Truxal; Rcho San Ramón, 13 mi N Cabo San Lucas, 24-VI-1994, F. Truxal.

Records from the literature.—BAJA CALIFORNIA SUR: Cape (Cabo) San Lucas, date unknown, John Xanthus (Uhler 1894). Uhler (1894) misidentified his specimens as *N. undulata* Say (*fide* Hungerford 1933), a species that is generally found north of 37°N latitude and often confused with *N. indica* that "replaces" it south of parallel 37.

Notonecta unifasciata Guérin-Méneville 1857

This species was first described from a series taken near Mexico, D.F. Published records cite it from western United States, western Canada, and mainland Mexico. Previous to the present study, no records from the Baja California peninsula have been cited and in the present case, it is reported only from the northern state of Baja California.

It is a species of moderate size measuring 9–10 mm in length and 3–3.6 mm in width. General facies are typically black and white as in the preceding species (*indica*), but varies from white to nearly black. Although it often is confused with *N. indica,* it is easily distinguished from that species by possessing an acutely-angled middle trochanter in the male and terminal abdominal sternite of the female broad and not plainly notched at tip as in *N. indica.*

Distribution.—BAJA CALIFORNIA: Laguna Hanson, 23-V-1959 & 2-VI-1960, E. Sleeper (LBSU) & 13-VIII-1993, F. Truxal; Agua Amarga, 18 mi W Bahía de Los Angeles, 6-VIII-1993, F. Truxal; 7 mi N Rosarito, 7-VI-1990, F. Truxal; 24 mi S Punta Prieta, 6-VIII-1993, F. Truxal.

Notonecta melaena Kirkaldy 1897

This species was first described as a variety of *N. shooterii* Uhler from a specimen taken on mainland Mexico. Published records cite it from the States of Jalisco and Guanajuato on the Mexican mainland and from Comondú and Las Parras in the state of Baja California Sur on the peninsula.

It is a species of moderate size measuring 10.8–11.7 mm in length and 4–4.3 mm in width, and is bichromatic. Pale luteus specimens have a slightly orange coloration while the dark pigmented forms are light red-brown to nearly black.

Distribution.—BAJA CALIFORNIA SUR: Rcho San José de Castro, Viscaíno sub-peninsula, 10-VIII-1993, F. Truxal; 20 mi N Comondú, 23-VII-1938, A. Michelbacher & E. Ross (CAS); Comondú, 19-XI-1956, C. Harbison (SDM); San Pedro de la Presa, 12-XI-1991, F. Truxal; Primera Agua, 37 mi NE Las Pocitas, 25-VI-1994, F. Truxal; Rcho El Huatamote, 13 mi W Primera Agua, 25-VI-1994, F. Truxal.

Records from the literature.—BAJA CALIFORNIA SUR: Comondú, Mar., 1889, C. Haines (Uhler 1894), misidentified as *N. mexicana* Amyot & Serville by Uhler (*fide* Hungerford 1993); Las Parras, date unknown, W. Mann (Hungerford 1933).

Key to *Buenoa* of Lower California
Based on Males

1. Front femur without stridulatory area .... *thomasi* Truxal
   Front femur with stridulatory area 2
2. Femoral stridulatory area with four or five sclerotized ridges .. *omani* Truxal
   Femoral stridulatory area with ten or more sclerotized ridges 3
3. Large, at least 8 mm in length; pronotum greatly inflated .... *arizonis* Bare
   Smaller, less than 8 mm in length; pronotum not inflated 4
4. Tylus with wide median depression forming two short lateral carinae...... .... *albida* (Champion)
   Tylus smooth without depression 5
5. Rostral prong originating at distal end of third rostral segment and distinctly longer than third rostral segment .... *platycnemis* (Fieber)
   Rostral prong originating midway of, or at proximal end of third rostral segment, and shorter than third rostral segment 6
6. Front femur with long, conspicuous, sword-shaped stridulatory area consisting of more than forty sclerotized ridges .... *scimitra* Bare
   Front femur with small, subtriangular to oval stridulatory area consisting of less than twenty-five sclerotized ridges ...... *margaritacea* Torre-Bueno

Genus *Buenoa* Kirkaldy 1904

The species of this genus are limited in their distribution to the Western Hemisphere and range from Canada, through the United States (including Hawaii), Mexico, Central America, West Indies, and South America. The species of *Buenoa* show greatest diversity in tropical South America where 37 of the approximately 55 species are recorded. Seven species are here recorded for the Baja California peninsula (Figs. 7, 8).

Buenoa arizonis Bare 1928

This species was first described from a series taken from the Superstition Mountains in Arizona, the only state in the United States from which it has been recorded. It has been recorded from mainland Mexico, as far south as the state of Guerrero. Although this species has not been recorded previously by name from Lower California, Uhler (1894) refers to a no longer extant, unidentified specimen of "unusually large size" taken at Comondú that I assume was *B. arizonis* since this is the largest species of the genus from the peninsula. I found it to be the most common species throughout Lower California (most numerous by far in Baja California Sur).

It is a large species measuring 8.4–8.8 mm in length and 2.6–2.8 mm in width, with general facies testaceous to dark brown.

Distribution.—BAJA CALIFORNIA: Bahía de Los Angeles, 17-IV-1940, C. Harbison (SDM); "Barcel", 27-III-1947, C. Harbison (SDM); Mission San Borja, 9-VI-1990, F. Truxal. BAJA CALIFORNIA SUR: San Francisco, N San Ignacio, 7-XI-1991, F. Truxal; El Mezquital, E San Ignacio, 10-X-1967, C. Harbison (SDM); 17 mi W Santa Rosalía, 18-VI-1967, E. Sleeper & F. Moore (LBSU); Santa Rosalía, 26-VI-1961, J. Honey; 5 mi S Santa Rosalía, 11-X-1972, E. Fisher (LBSU); San Ignacio, 8-VI-1990, F. Truxal; Santa Agueda, nr Santa Rosalía, 8-X-

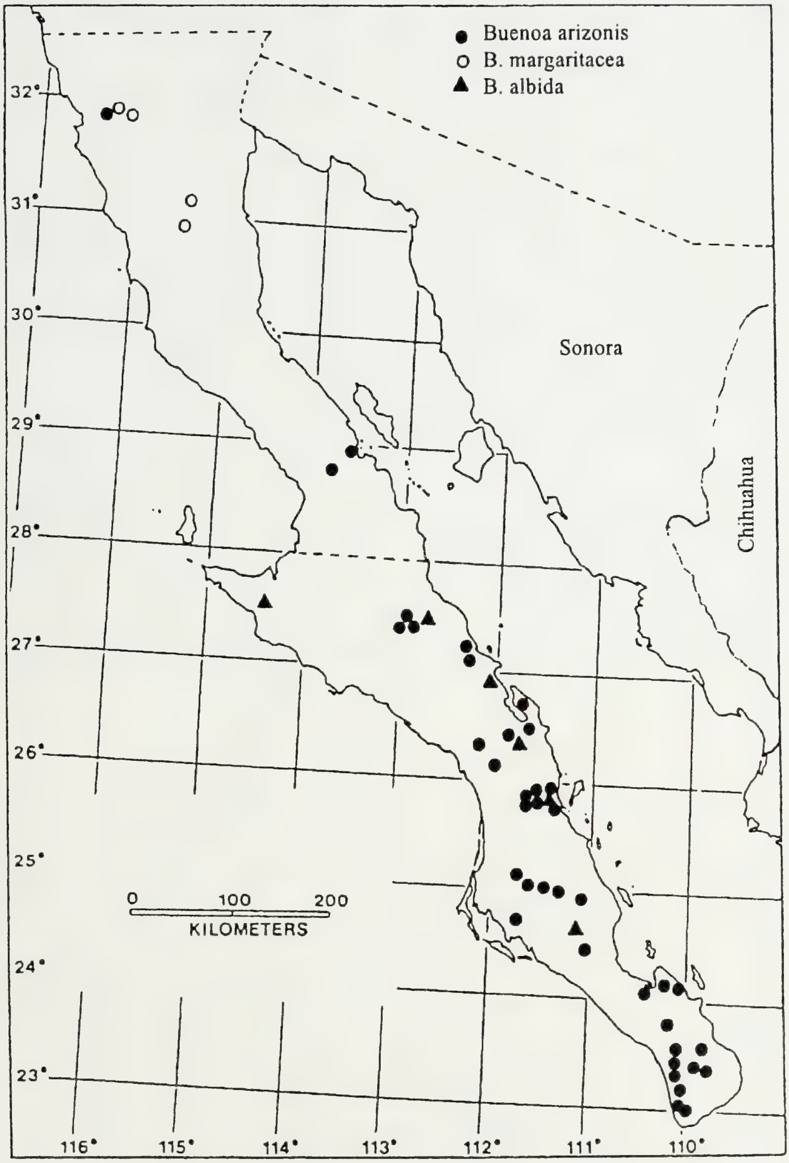

Fig. 7. Distribution of *Buenoa* in Lower California. Closed circles *B. arizonis,* open circles *B. margaritacea,* closed triangles *B. albida.*

1988, F. Truxal; 5 mi N Mulegé, 14-X-1983, F. Andrews & D. Faulkner (SDM); El Salto, E shore Bahía Concepción, 10-XI-1991, F. Truxal; south shore Bahía Concepción (stock tank), 10-XI-1991, F. Truxal; San Isidro Rd, 9 mi W Hwy 1, nr Loreto, 11-XI-1991, F. Truxal; San Isidro Rd, 10 mi W Hwy 1, 9-X-1988, F. Truxal; 5 mi N San Isidro, 18-VII-1986, N. Bloomfield (SDM); Comondú, 25-XI-1941 & 16-XI-1956, C. Harbison (SDM); Primera Agua, 7 km W Loreto, 10-VII-1990, F. Truxal; Las Parras-San Javiér Rd, 11-XI-1991, F. Truxal; Rcho Viejo, arroyo Santo Domingo, nr San Javiér, 17-XII-1956, I. Wiggins (CAS); 4 mi S

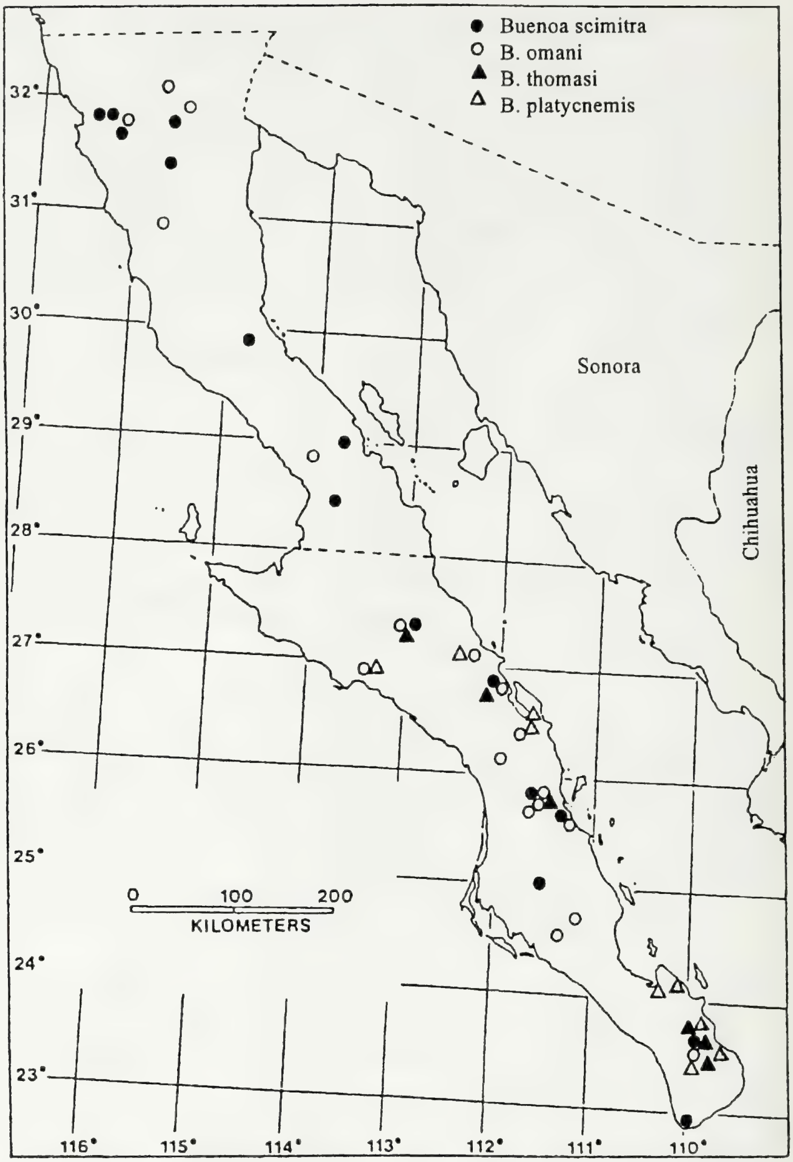

Fig. 8. Distribution of *Buenoa* in Lower California. Closed circles *B. scimitra,* open circles *B. omani,* closed triangles *B. thomasi,* open triangles *B. platycnemis.*

Mission San Javiér, 19-V-1969, S. Williams (CAS); Puerto Escondido, 7-IV-1962, C. Harbison (SDM) & 14-VI-1921, J. Chamberlin (CAS); Ciudad Constitución (swim. pool), 11-XI-1991, F. Truxal; Presa El Ilhuajel, 15 mi E Villa Morelos, 11-XI-1991, F. Truxal; Mission San Luís Gonzaga, 25 mi E Villa Morelos, 12-XI-1991, F. Truxal; Rd to San Pedro de la Presa, 28 mi E Hwy 1, 12-XI-1991, F. Truxal; San Pedro de la Presa, 31.7 mi E Hwy 1, 12-XI-1991, F. Truxal; Primera Agua, 37 mi NE Las Pocitas, 25-VI-1994, F. Truxal; 7 mi NE Las Pocitas, 25-VI-1994, F. Truxal; San Hilario (El Cíen), 5-XI-1968, E. Sleeper & F. Moore (LBSU)

& 12-XI-1959, I. Wiggins (CAS); 12.4 mi E La Paz, Rd to Las Cruces, 4-I-1959, H. Leech (CAS); La Paz, 28-X-1946, Y. Dawson; La Huerta, 15 mi SE La Paz, 8-IX-1989, F. Truxal; San Bartolo, 8-IX-1989, F. Truxal; 1 mi SE San Bartolo, arroyo San Bartolo, 20-I-1959, H. Leech (CAS); 5 mi W San Bartolo, 13-VII-1938, A. Michelbacher & E. Ross (CAS); San Antonio de la Sierra, Sierra de la Laguna, 24-VI-1994, F. Truxal; 5.5 mi SE Valle Perdido, 14-15-X-1968, E. Sleeper & F. Moore (LBSU); El Salto, 8 mi NE Todos Santos, 9-X-1983, F. Andrews & D. Faulkner (SDM); Presa Santa Inés, 5.2 mi N Todos Santos, 13-XI-1991, F. Truxal; 3 mi E La Burrera, E Todos Santos, 17-19-X-1968, E. Sleeper & F. Moore (LBSU); Rcho Halada, 5 mi SE Todos Santos (stock tank), 9-IX-1989, F. Truxal; Boca de la Sierra, 5-III-1969, R. Snelling & 19-I-1959, I. Wiggins & H. Leech (CAS); 5 km NW Miraflores, 11-XI-1979, G. Challet (LBSU); Rcho El Palmar, 2.5 mi E Hwy 19, S Todos Santos, 20-X-1972, E. Fisher (LBSU); Rcho San Ramón, 13 mi N Cabo San Lucas, 24-VI-1994, F. Truxal.

Records from the literature.—BAJA CALIFORNIA SUR: Comondú, Mar., 1889, C. D. Haines. Uhler (1894) states "a specimen of unusually large size was taken." As noted above, *B. arizonis* is the largest species of *Buenoa* from the Baja California peninsula so I assume that the unidentified species referred to by Uhler was *arizonis*. This specimen, originally deposited in the California Academy of Sciences, was reportedly destroyed during the 1906 San Francisco earthquake.

Buenoa omani Truxal 1953

This species was first described from series taken in southern California and Durango, Mexico. Published records cite it from southern California and from the state of Sonora south to the state of Chiapas on the Mexican mainland. There are no previous records from Lower California, although the following data on distribution indicate its presence in both states of the peninsula.

It is a species of moderate size measuring 5.72–6.69 mm in length and 1.62–2.08 mm in width. General facies varies from sordid white to nigro-violaceous.

Distribution.—BAJA CALIFORNIA: Guadalupe Canyon, 22-II-1959, E. Sleeper (LBSU) & 5-X-1988, F. Truxal; 66 mi SE Ensenada, 30-I-1968, E. Sleeper (LBSU); Meling Ranch (San José), 11-X-1988, F. Truxal; 20 mi N Punta Prieta, 21-IV-1962, C. Harbison (SDM). BAJA CALIFORNIA SUR: San Ignacio, 14-III-1984, E. Larsen (UA) & 8-VI-1990, F. Truxal; Santa Agueda, nr Santa Rosalía, 8-X-1988, F. Truxal; Mulegé, 27-II-1969, K. Stager; south shore Bahía Concepción (stock tank), 10-XI-1991, F. Truxal; 2 mi E Canipolé, 12-XI-1968, E. Sleeper & F. Moore (LBSU); San Javiér Rd, 9 mi W Hwy 1, 11-XI-1991, F. Truxal; 2.7 mi S Ejido Cadejé, N La Purísima, 9-VIII-1993, F. Truxal; Comondú, 19-XI-1956, C. Harbison (SDM); 11 mi E San Javiér, 12-V-1987, F. Truxal; 2.5 mi E Las Parras, 28-II-1969, K. Stager; Puerto Escondido, 7-IV-1962, C. Harbison (SDM); 21 mi W San Javiér, 1-III-1969, K. Stager; Rcho El Huatamote, 13 mi W Primera Agua, 25-VI-1994, F. Truxal; 7 mi NE Las Pocitas, 25-VI-1994, F. Truxal; La Laguna (Sierra de la Laguna), 21-V-1965, A. Sloan (LBSU); 3 mi E La Burrera, 17-19-X-1968, E. Sleeper & F. Moore (LBSU); Boca de la Sierra, 5-6-III-1969, R. Snelling.

Buenoa scimitra Bare 1925

This species was first described from series taken from Douglas County, Kansas and Colorado County, Texas. Published records cite it from the southern half of the United States, central mainland Mexico and the West Indies. Previous to the present study, no records existed for this species from Lower California where it was found in both states.

It is a species of moderate size measuring 5.46–7.50 mm in length and 1.56–2.15 mm in width. General facies are sordid white to fuscous.

Distribution.—BAJA CALIFORNIA: Laguna Hanson, 23-V-1959, E. Sleeper (LBSU) & 13-VIII-1993, F. Truxal; 25 mi E Ojos Negros, 6-IV-1961, F. Truxal; 66 mi SE Ensenada, 24-III-1960, E. Sleeper (LBSU); 4 mi NE El Mayor, NE Ensenada, 22-I-1981, J. Brown & D. Faulkner (SDM); 3 mi S La Zapopita, Valle de Trinidad, 10-IV-1961, F. Truxal; 12 mi S El Mármol, 12-IX-1989 & 27-IV-1992, F. Truxal; Agua Amarga, 18 mi W Bahía de Los Angeles, 6-VIII-1993, F. Truxal; 20 mi S Punta Prieta, Hwy 1, 6-VIII-1993, F. Truxal. BAJA CALIFORNIA SUR: San Ignacio, 8-VI-1990, F. Truxal; 5 mi N Mulegé (black light), 14-X-1983, F. Andrews & D. Faulkner (SDM); Rcho Viejo, arroyo Santo Domingo, nr San Javiér, 17-XII-1956, I. Wiggins (CAS); Presa El Ilhuajel, 15 mi E Villa Morelos, 11-XI-1991, F. Truxal; 1 mi SE San Bartolo, arroyo San Bartolo, 20-I-1959, H. Leech (CAS); 2 mi NE Cabo San Lucas, 16-I-1959, H. Leech (CAS).

Buenoa margaritacea Torre-Bueno 1884

This species was described from specimens taken in Maryland. Published records cite it from throughout the United States, Canada, and from the northern mainland of Mexico in the States of Chihuahua, Coahuila and Tamaulipas. *Buenoa margaritacea* has not been reported previously from Lower California. During the present study it was found at four sites in the northern part of the state of Baja California.

It is a species of moderate size but variable, measuring 6–8.2 mm in length and 1.50–2.40 mm in width. General facies are sordid white to dark brown in color.

Distribution.—BAJA CALIFORNIA: 48 mi SE Ensenada, 17-IV-1960, E. Sleeper (LBSU); 1 mi W San Matías Pass, 7-VI-1961, E. Sleeper (LBSU); Vallecitos, San Pedro Mártir Nat. Park, 13-IX-1989, F. Truxal; "Barcel", 27-III-1947, C. Harbison (SDM).

Buenoa thomasi Truxal 1953

This species was first described from specimens taken at two localities in the state of Chihuahua, Mexico that, previous to this study, were the only known recorded localities. In the present case, six localities in the southern state of Baja California Sur are cited.

It is a species of small to medium size measuring 5.26–6.04 mm in length and 1.49–1.82 mm in width, with general facies sordid white to gray. This species is the only one from Lower California that lacks the femoral stridulatory area.

Distribution.—BAJA CALIFORNIA SUR: San Ignacio, 14-III-1984, E. Larsen (UA) & 8-VI-1990, F. Truxal; Mulegé, 27-II-1969, K. Stager; San Javiér Rd, 9 mi W Hwy 1, 11-X-1991, F. Truxal; San Bartolo, 8-IX-1989, F. Truxal; 2.7 mi SE Valle Perdido, 15-16-X-1968, E. Sleeper & F. Moore (LBSU); Boca de la

Sierra, nr Miraflores, 27-28-VI-1967, E. Sleeper & E. Fisher (LBSU) & 5-III-1969, R. Snelling.

Buenoa albida (Champion) 1901

This species was first described from a series of specimens taken from the state of Veracruz, Mexico. Published records cite it from Texas, Mexico from Sonora south to Guerrero, and in Puerto Rico. The present study records it from six sites in Lower California in Baja California Sur.

It is a small species measuring 5.85–6.60 mm in length and 1.69–1.82 mm in width, with general facies sordid white.

Distribution.—BAJA CALIFORNIA SUR: Rcho San José de Castro, Viscaíno sub-peninsula, 10-VIII-1993, F. Truxal; San Ignacio, 14-III-1984, E. Larsen (UA); south shore Bahía Concepción (stock tank), 3 mi E Hwy 1, 10-XI-1991, F. Truxal; 2 mi E Canipolé, 12-XI-1968, E. Sleeper & F. Moore (LBSU); 9 mi W Hwy 1, San Javiér Rd, 11-XI-1991, F. Truxal; Rcho El Huatamote, 13 mi W Primera Agua, 25-VI-1994, F. Truxal.

Buenoa platycnemis (Fieber) 1851

This species was first described from specimens taken from Puerto Rico, West Indies. Published records cite it from Texas and Florida in the United States, throughout mainland Mexico, West Indies, Central America and the northern half of South America. The present study records it for the first time from seven sites on the peninsula, all in Baja California Sur.

It is a small species measuring 4.55–5.43 mm in length and 1.36–1.75 mm in width. General facies range from sordid white to black.

Distribution.—BAJA CALIFORNIA SUR: San José de Magdalena, 8-VIII-1993, F. Truxal; south shore Bahía Concepción, 3 mi E Hwy 1 (stock tank), 10-XI-1991, F. Truxal; 2 mi E Canipolé, 12-XI-1968, E. Sleeper & F. Moore (LBSU); 2.7 mi S Ejido Cadejé, N La Purísima, 9-VIII-1993, F. Truxal; La Paz, 6-X-1968, E. Sleeper & F. Moore (LBSU); Arroyo Saltito, nr Las Cruces, E of La Paz, 23-I-1959, H. Leech (CAS); 12 mi SE San Bartolo, 7-IX-1965, W. Ewart & R. Dickson (LBSU); El Chorro, nr Agua Caliente, Sierra de la Laguna, 29-30-X-1968, E. Sleeper & F. Moore (LBSU); Boca de la Sierra, 3 mi NW Miraflores, Cañon San Bernardino, 19-I-1959, I. Wiggins & Leech (CAS).

Excluded Species

I have excluded two species of *Notonecta* (*mexicana* Amyot & Serville and *undulata* Say) and one species of *Buenoa* (*elegans*) that are cited in the literature as occurring in Lower California. These three species are excluded for the following reasons.

Uhler (1894) recorded *Notonecta mexicana* and *N. undulata* from Lower California. Hungerford (1933) stated that Uhler had misidentified the material and that his *mexicana* specimens from El Paraiso are actually *N. hoffmani* while his *mexicana* specimens from Comondú are *N. melaena*. Uhler's specimens of *N. undulata* from Cape San Lucas are actually *N. indica* according to Hungerford.

Uhler, in the same paper cited above, records *Anisops elegans* Fieber as having been collected at Cape San Lucas by John Xanthus. Kirkaldy (1904) placed all Western Hemisphere *Anisops* in the genus *Buenoa*, retaining the name *Anisops* for the Eastern Hemisphere species. Truxal (1953), upon examining the type specimen of *A. elegans* Fieber, found it to be a true *Anisops* and sent it to a colleague, G. W. Brooks, who found the specimen to be *A. apicalis* Stål, an African species. Truxal found that specimens masquerading under the name *Buenoa elegans* (Fieber) and known to generations of entomologists as this species were actually an undescribed species which he proceeded to describe and name *Buenoa confusa* (1953). Since the Uhler specimens from Cape San Lucas are no longer extant and *B. confusa* has been recorded only from Canada, United States and Grand Cayman Island in the West Indies, I am inclined to believe that Uhler once again misidentified his specimens in the 1894 paper. I suspect that his specimens might have been *B. platycnemis* (Fieber), a similar species found in the same area of Lower California as his "*elegans.*"

Discussion

The family Notonectidae has received limited attention on the Baja California peninsula. The primary reason for undertaking the current study was to close this gap in our knowledge concerning the presence and distribution of notonectids on this large but relatively isolated peninsula on the North American continent. In searching the literature and collections for records of Notonectidae from Lower California, I was struck by the almost non-existence of material relative to this family. I suspected that the scarcity of information was due to the lack of field work concentrating on these insects. The results of the study have confirmed my suspicion.

Of the four genera of notonectids known to occur in the Western Hemisphere (*Notonecta, Buenoa, Martarega, Enitharoides*), two, *Notonecta* and *Buenoa,* are recorded from Lower California. Previous to the present study, six localities on the peninsula had been cited in the literature. After searching institutional collections and conducting extensive field work in collaboration with Dr. Harry Brailovsky of the Universidad Nacional Autonoma de Mexico, a total of approximately 100 localities in Lower California were found that produced notonectids. These sites yielded 13 species in the two genera.

Notonecta is a cosmopolitan genus with approximately 47 recognized species in the Western Hemisphere with a geographical census approximately as follows: Canada, 8; United States, 18; Mexico, 22; Central America, 4; West Indies, 2; South America, 20. Hungerford (1933) considers *Notonecta* to be the most primitive of the notonectid genera, taking into account both biogeographical data as well as morphological characteristics. Of the six species found on the Baja California peninsula, five, *hoffmani, kirbyi, indica, shooterii, unifasciata,* occur in southern California and in the northern state of Baja California, with *hoffmani, indica,* and *shooterii* found in both peninsular states. Only one of the six peninsular species, *melaena,* from Baja California Sur, is absent from the United States; it occurs on the Mexican mainland as far south as the state of Jalisco. *Notonecta hoffmani, kirbyi,* and *shooterii* have not been recorded from the mainland of Mexico.

Buenoa is confined to the Western Hemisphere and is considered by Hungerford (1933) and Truxal (1953) to be a member of the most specialized notonectid subfamily, Anisopinae. There are approximately 55 species currently recognized in the genus with a distribution as follows: Canada, 4; United States, 16; Mexico, 17; Central America, 7; West Indies, 13; South America, 37. Of the seven species found on the Baja California peninsula, only three, *margaritacea, scimitra,* and *omani,* are known to occur in southern California, while two others, *arizonis* from Arizona and *platycnemis* from Texas and Florida complete the complement of United States species found on the peninsula. Of these five species, *margaritacea* is found only in the state of Baja California and *platycnemis* only in Baja California Sur, while three, *scimitra, omani,* and *arizonis* are found in both peninsular states. Three species of the genus, *platycnemis* (as noted above), *albida,* and *thomasi* are restricted on the peninsula to Baja California Sur. All seven peninsular species are found on the Mexican mainland, with *B. platycnemis* having the greatest north-south distribution (Texas and Florida in the U.S., south to northern South America). I suggest that at least the three species, *albida, thomasi,* and *platycnemis* managed a Trans-Gulfian crossing from the mainland of Mexico. All three have been taken in the Río Mayo of Sonora and Chihuahua on the mainland. The Río Mayo enters the Gulf of California near the town of Huatabampo, Sonora, which is only about 201 kilometers across the Gulf to the area of Bahía Concepción, Baja California Sur. Members of this genus are relatively vagile and fly considerable distances without suffering dessication and death. As Hutchinson (1981) points out, "In transient environments, which nearly all bodies of freshwater are, some opportunity for dispersal is necessary for continued existence of a species." In addition to the proximity of the Mexican mainland to the peninsula, the prevailing southwesterly winds of the annual moist tropical storms and hurricanes that blow across the mainlands of Mexico, Central America and the peninsula could be a significant aid in Trans-Gulfian migration. It is reasonable to assume that chances of this method of species dispersal to the peninsula without great danger of dessication is possible.

I have relied on a biogeographic analysis of living species to speculate on possible origins and dispersal patterns of *Notonecta* and *Buenoa* in the New World that might in turn account for their current status in Lower California. This analysis takes into account the morphological characters of the current species and the present geographical distribution of these species.

The "numerical" method of determining the origin of an organism is widely accepted by biogeographers to determine the direction of dispersal of an organism (Ross, 1974). This method implies that a group probably originated in the area where greatest diversity exists and it is on this principle that I have based my suggested origins and dispersal patterns of *Notonecta* and *Buenoa* in the Western Hemisphere. Although Ross states that this approach is not always universally true, under the present circumstances regarding the knowledge of phylogeny and historical geology on notonectids, it seems the best that can be applied at this time. It certainly can form the basis for future study on the subject. It should be stated that the method I have chosen is only one of several possible ways of hypothesizing "center of origin." As Humphries and Parenti (1986) point out, in addition to the "numerical" method, other concepts include "the area in which the most primitive forms occur, the area occupied by the most phylogenetically advanced or primitive members or where the oldest fossils occur." Vicariance biogeography is currently a concept that is widely accepted.

In general, the area of greatest taxonomic diversity for *Notonecta* is tropical Mexico, Central and South America and for *Buenoa,* tropical South America.

Therefore, I propose a Neotropical origin for these two genera as relates to the Western Hemisphere, with dispersal north to the Nearctic during a period when a warmer and more humid environment existed in the north. Subsequently, with a cooling climate and more arid conditions that came to prevail in the north, one might speculate that a secondary migration southward occurred for those species unable to adapt to the new environment. Species of the genus *Buenoa,* and probably *Notonecta,* are certainly influenced in their current distribution by cold. As an example, *Buenoa* is presently confined geographically to an area generally between 52°N latitude in Canada and 52°S latitude in Argentina. I assume that as the cold climate progressed southward during the Tertiary, these insects also were pushed southward.

Finally, due to the recent interest in a "peninsular effect" principle originally proposed by Simpson (1964) that relates to the dispersal of organisms on the World's peninsulas, and in the present case on the Baja California peninsula, it might be of interest to comment briefly on this principle as it relates to the Notonectidae. As pointed out by Brown and Opler (1990), "The 'peninsular effect' is a biogeographic principle that can be summarized as follows: Species density (richness) decreases as a function of distance from the mainland base (towards the distal tip) of a peninsula." These authors further state that "although initially supported by studies on North American vertebrates (Simpson 1964; Cook 1969; Kriester 1971; Taylor and Regal 1978), recent investigations on a wide array of organisms (Seib 1980; Gilpin 1981; Busack and Hedges 1984; Due and Polis 1986; Means and Simberloff 1987; Brown, 1987; Schwartz, 1988) have demonstrated that the peninsular effect is not a general pattern but an occasional phenomenon exhibited by select taxa on select peninsulas." Several authors who have concentrated on arthropods from the Baja California peninsula, including Due and Polis (1986), Brown (1987), and Brown and Donahue (1989), have found that the organisms they studied did not conform to the principle. Likewise, as noted elsewhere in my results, I have found patterns that suggest both a southward dispersal (particularly in *Notonecta*) as well as a northward dispersal (particularly *Buenoa*) as relates to the peninsula's Notonectidae. Therefore, I suggest that my findings do not conform to the peninsular effect principle as originally proposed.

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Appendix. Collecting sites with geographic coordinates arranged sequentially from north to south.

	Coordinates	
Localities	North Lat.	West Long.
ESTADO DE BAJA CALIFORNIA		
1. El Tajo Canyon	32°17′	115°56′
2. 2.2 mi SE El Topo	32°14′	115°58′
3. 2.7 mi SW Ejido Ignacio Zaragosa, Hwy 3	32°11′	116°29′
4. Guadalupe Canyon	32°09′	115°48′
5. Laguna Hanson	32°03′	115°54′
6. 3.6 mi SE El Rayo, nr Laguna Hanson	31°58′	115°58′
7. 25 mi E Ojos Negros	31°55′	116°10′
8. 10 mi E Ojos Negros	31°55′	116°07′
9. 2 mi E El Progreso, nr Ojos Negros	31°55′	116°17′
10. 2 mi E Ojos Negros	31°54′	116°16′
11. 34 mi SE Ensenada	31°53′	116°24′
12. 48 mi SE Ensenada	31°53′	116°20′
13. 66 mi SE Ensenada	31°53′	116°16′
14. El Mayor, 4 mi NE Ensenada	31°53′	116°32′
15. El Paraiso, nr Ojos Negros	31°53′	116°17′
16. Ensenada	31°52′	116°35′
17. Arroyo Santo Tomás	31°33′	116°24′
18. 3 mi S La Zapopita, Valle de Trinidad	31°25′	115°41′
19. 20 mi S Santo Tomás	31°23′	116°18′
20. 1 mi W San Matías Pass	31°20′	115°34′
21. Vallecitos, San Pedro Mártir National Park	31°01′	115°28′
22. Meling Ranch (San José)	30°58′	115°45′
23. San Pedro Mártir National Park Hdqts.	30°58′	115°35′
24. Canyon del Cabane (Cañada El Novillo)	30°53′	115°15′
25. San Fernando Mission, 40 mi S El Rosario	29°58′	115°14′
26. 6 mi SW El Mármol	29°57′	114°54′
27. Santa María (Mission nr Cataviña)	29°44′	114°33′
28. Agua Amarga, 18 mi W Bahía de Los Angeles	29°02′	113°49′
29. Bahía de Los Angeles	28°57′	113°34′
30. 20 mi N Punta Prieta	28°56′	114°10′
31. Mission San Borja	28°44′	113°50′
32. 7 mi N Rosarito	28°43′	114°05′
33. 24 mi S Punta Prieta	28°38′	114°01′
34. Mission Santa Gertrudis, nr El Arco	28°03′	113°05′
ESTADO DE BAJA CALIFORNIA SUR		
1. San Francisco, N San Ignacio	27°36′	113°01′
2. Rcho San José de Castro (Viscaíno sub-penins.)	27°32′	114°28′
3. El Mezquital, 10 mi E San Ignacio	27°25′	112°35′
4. 17 mi W Santa Rosalía	27°23′	112°28′
5. Santa Rosalía	27°20′	112°17′
6. 5 mi S Santa Rosalía	27°17′	112°15′
7. San Ignacio	27°17′	112°54′
8. Santa Agueda	27°16′	112°21′
9. San José de Magdalena	27°04′	112°14′
10. 5 mi N Mulegé	26°56′	112°02′
11. Mulegé	26°53′	111°59′
12. El Salto, E shore Bahía Concepción	26°42′	111°46′
13. South shore Bahía Concepción (stock tank)	26°33′	111°42′
14. 2 mi E Canipolé	26°25′	111°40′

Appendix. Continued.

	Coordinates	
Localities	North Lat.	West Long.
15. 9 mi W Hwy 1 on San Javiér Rd	26°24′	111°04′
16. 10.5 mi W Hwy 1 on San Javiér Rd	26°22′	111°43′
17. 2.7 mi E Ejido Cadejé, N La Purísima	26°20′	112°30′
18. 5 mi N San Isidro	26°16′	112°07′
19. 14 mi N Loreto	26°13′	111°26′
20. 20 mi N Comondú	26°09′	112°08′
21. Comondú	26°03′	111°26′
22. Primera Agua, 7 mi W Loreto	26°00′	111°26′
23. 11 mi E San Javiér	25°59′	111°27′
24. 2.5 mi E Las Parras	25°58′	111°29′
25. Rcho Viejo, arroyo Santo Domingo, nr San Javiér	25°56′	111°33′
26. 4 mi S Mission San Javiér	25°50′	111°33′
27. Puerto Escondido	25°47′	111°19′
28. 1 mi S Puerto Escondido	25°47′	111°19′
29. 1 mi SW Palo Blanco, nr San Javiér	25°39′	111°36′
30. 21 mi W San Javiér	25°35′	111°38′
31. Ciudad Constitución (swimming pool)	25°02′	111°40′
32. Presa El Ilhuajel, 15 mi E Villa Morelos	24°59′	111°24′
33. Mission San Luís Gonzaga, 25 mi E Villa Morelos	24°54′	111°17′
34. Rd to San Pedro de la Presa, 28 mi E Hwy 1	24°53′	111°16′
35. San Pedro de la Presa, 31.7 mi E Hwy 1	24°51′	110°59′
36. Primera Agua, 37 mi NE Las Pocitas	24°51′	110°47′
37. Rancho El Huatamote, 13 mi W Primera Agua	24°41′	110°41′
38. 7 mi NE Las Pocitas	24°29′	111°04′
39. San Hilario (El Cién)	24°21′	111°00′
40. 12.4 mi E La Paz, Rd to Las Cruces	24°14′	110°09′
41. Arroyo Saltito nr Las Cruces, E of La Paz	24°14′	110°08′
42. La Paz	24°08′	110°20′
43. La Huerta, nr La Paz	24°03′	110°10′
44. 5 mi W San Bartolo	23°44′	109°53′
45. San Bartolo	23°44′	109°51′
46. 1 mi SE San Bartolo, arroyo San Bartolo	23°44′	109°50′
47. 12 mi SE San Bartolo	23°41′	109°42′
48. 2.7 mi SE Valle Perdido	23°41′	110°06′
49. San Antonio de la Sierra, nr San Antonio	23°41′	109°57′
50. 5.5 mi SE Valle Perdido, nr San Antonio	23°40′	110°06′
51. La Laguna (La Laguna mts, 5500′ elev.)	23°33′	109°59′
52. Presa Santa Inés, 5.2 mi N Todos Santos	23°32′	110°09′
53. 3 mi E La Burrera, nr Todos Santos	23°31′	110°03′
54. El Chorro, nr Agua Caliente	23°27′	109°48′
55. Todos Santos	23°27′	110°13′
56. Rancho Halada, nr Todos Santos	23°26′	110°10′
57. Boca de la Sierra	23°23′	109°49′
58. 5 km NW Miraflores	23°23′	109°49′
59. Rancho El Palmar, S Pescadero	23°16′	110°08′
60. San José del Cabo	23°03′	109°42′
61. Rancho San Ramón, 13 mi N Cabo San Lucas	23°03′	109°59′
62. 7.7 mi NE Cabo San Lucas, Hwy 19	22°58′	110°01′
63. 2 mi NE Cabo San Lucas, Hwy 19	22°54′	109°57′
64. Cape (Cabo) San Lucas	22°53′	109°55′

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Inheritance of the Call of the Bullfrog, *Rana catesbeiana*

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Introduction

Vocal communication is an important characteristic of birds, frogs and insects (Alexander 1962). In several studies of song learning in birds (e.g., Bottjer and Arnold 1986; Bottjer 1991; Slater, Eales and Clayton 1988), young birds raised with conspecifics produce a song similar to that of a member of their particular species. Therefore, young birds raised with adults of their own species are more apt to produce the species correct song. In a collorary study, adult zebra finches that had been deafened showed only minor changes in the song they had learned as nestlings (Price 1979). Therefore, timing is important in the development of the species' typical song. The conclusion from these studies is that while the fine details of song are learned during a "critical" or sensitive phase of development, there are genetically determined limits to the song pattern bird will sing. Young birds raised in acoustic isolation or deafened and raised only by the mother may never develop normal vocal behavior (Marler and Peters 1982; Nottebohm 1971).

Normally, frogs and insects do not have direct contact with adults of the same species, as do birds. It is supposed, therefore, that voice is strictly under genetic control with little or no learning. This assumption has not been tested, however, there is no reason to suppose that a frog raised from an egg, isolated from adults of the same species, would have a different call (Gerhardt 1994).

Materials and Methods

An individual tadpole from an egg mass laid on May 18, 1990 in a private lily pond in Ladera Heights, California, was raised to adulthood in a laboratory at the University of Southern California, Department of Biological Sciences. The mother of the experimental frog was collected in East Hartford, Connecticut (circa 1976) and the father was obtained from a biological supply company in Tennessee (circa 1987). The tadpole was fed a diet of ground fish meal every other day. After metamorphosis, the tadpole was fed a diet of crickets (*Gryllus domesticus*) dusted with calcium and Vitamin D, mealworms (*Tenebrio* larvae) and earthworms (*Lumbricus terrestris*) every other day. Calls from the experimental frog were recorded on a Realistic CTR-85 Voice Actuated Cassette tape recorder, using Memorex dBS cassette tapes, along with a Realistic Vox Clock that announced each hour. We also recorded a wild bullfrog mating call from the pond in which the egg was laid (the putative father of the laboratory-raised frog) as well as a wild bullfrog mating call from a Cornell recording (Voices in the Night) for comparison. The calls were analyzed on a Kay DSP sona-Graph Model 5500, Kay Gray Scale Printer Model 5311 and NEC Multisync II Monitor.

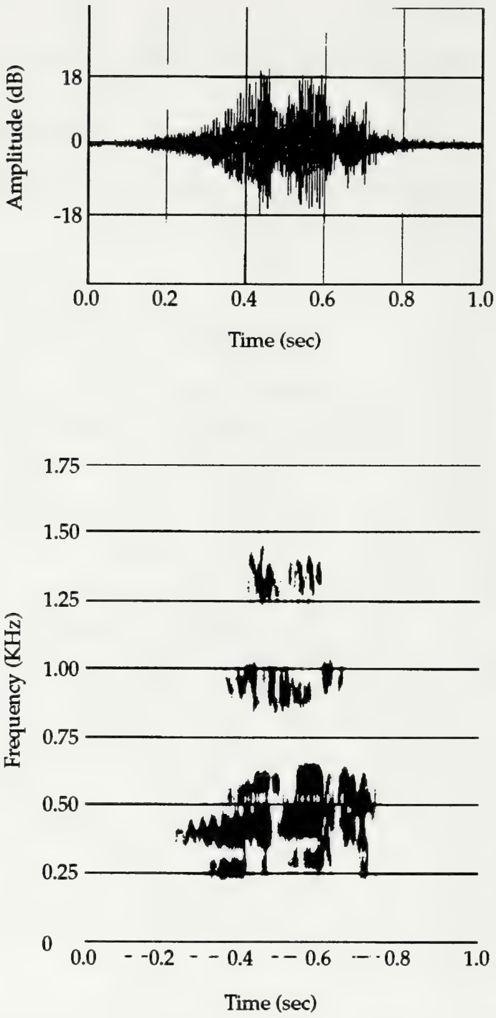

Fig. 1. Oscillogram (upper) and sonagram (lower) of a call of a laboratory-raised solitary male *Rana catesbeiana.*

Results

The tadpole metamorphosed 3 months after being laid. The individual experimental frog then began calling during the month of February 1991, approximately 6 months after metamorphosis. The frog was 10 centimeters snout-to-vent length. The prepared sonagrams of the experimental frog calls and those of the wild bullfrog calls, which appear in the following figures (Figs. 1–3), were compared with those published in Capranica (1965).

Discussion

We realize that the development of this bullfrog was unusually rapid; 3 months to metamorphosis and 6 months to calling. There would be an ecological advantage for early metamorphosis for this tadpole since it had no competition for

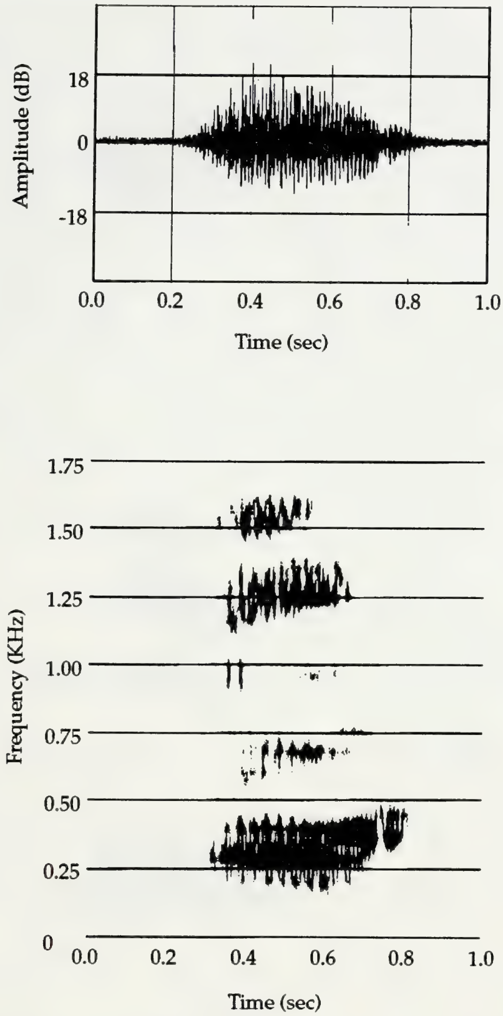

Fig. 2. Oscillogram (upper) and sonagram (lower) of a call of a wild male *Rana catesbeiana* recorded in Los Angeles.

resources. In addition, this early developmental pattern has been repeated in two other cases.

The calls of the experimental frog sounded to us to be typical of bullfrog advertisement calls. However, comparison of the sonagrams of the experimental frog with those of the adult wild frogs show that the isolate frog calls are different from both adults and those differences, the narrowing of the frequencies within the call, were consistent in all recordings. All of the sonagrams analyzed contained small differences in frequency and amplitude. The overall similarity of the calls, however, is evidence that there may be some learning or regional dialects involved in ranid calls. In addition, those differences could be no more than one would get from individuals of different sizes or at different temperatures.

It is of interest therefore to raise a frog in the following environments: 1) acoustic isolation; 2) with other conspecific adults; or 3) with adults of another

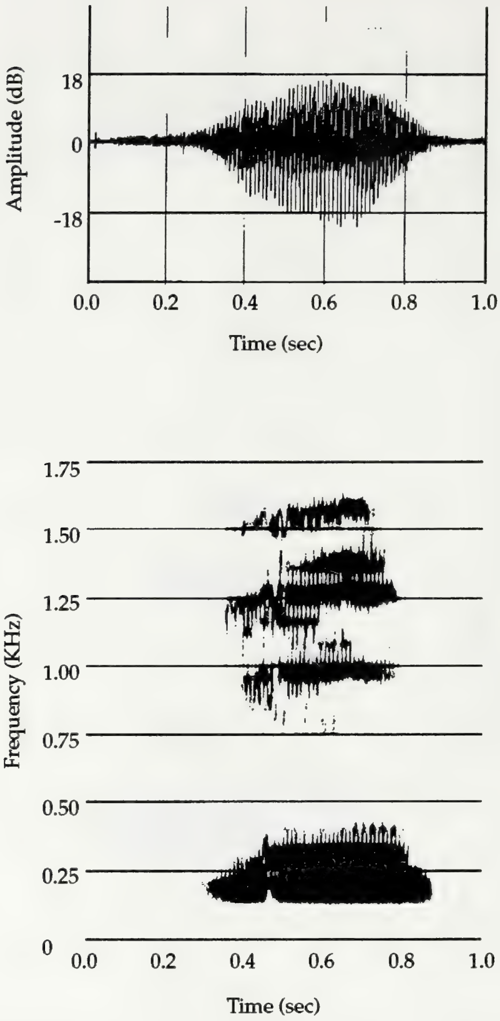

Fig. 3. Oscillogram (upper) and sonagram (lower) of a call of a wild male *Rana catesbeiana* ("Voices of the Night", Cornell University).

species that generally have different seasonal patterns for reproduction. These studies would be important to determine if the environment in which a frog is raised has an influence on the call as an adult. We plan to raise tadpoles with recordings of conspecific calls and raise other tadpoles and expose them to recordings of other *Rana* calls.

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Tidal Cycle Distortion in Carpinteria Salt Marsh, California

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Abstract.—Strong tidal distortion, consistent with descriptions of other flood tide-dominated shallow systems, was evident in tide gauge records from Carpinteria Salt Marsh (CSM), a 93 ha wetland in southern California. Daily tidal ranges in CSM were less than 50% of predicted values. Low tides levels were higher and varied less than predicted tides. Mean water level in CSM was higher than mean sea level. Ebb tide periods were extended by as much as several hours beyond predicted intervals, and flood tides were correspondingly shorter. Lowest tides in CSM frequently occurred at a time corresponding to predicted Higher Low Water.

Strong tidal distortion has been reported for estuaries, shallow embayments and other tidal systems on the east coast of North America (Aubrey and Speer 1985; Speer and Aubrey 1985; Fry and Aubrey 1990) and elsewhere (Robinson et al. 1983; Hill 1994). Temporal patterns of water levels in these shallow systems can differ from the tidal patterns in the nearby coastal ocean in range, amplitudes and phases of constituents, ebb and flood asymmetry, and mean water level (Robinson et al. 1983; Aubrey and Speer 1985; Hill 1994). Tidal distortion in shallow systems is caused by frictional attenuation of ocean tide constituents and non-linear growth of constituent harmonics (Speer and Aubrey 1985). Inlet channel and basin geometry modify the tidal forcing of the coastal ocean and may cause flood tide or ebb tide-dominated asymmetry.

Shallow systems with ratios of tidal amplitude (M2 tide component) to channel depth below mean sea level greater than 0.3, and without large tidal flats, tend to be flood tide-dominated (Aubrey and Speer 1985), with relatively high velocity, short duration flood tides and lower velocity, longer duration ebb tides. Mean water levels in flood tide-dominated systems may be elevated above mean sea level and may show fortnightly variation due to differences in frictional effects between neap and spring tide periods (Hill 1994).

In flood tide-dominated systems, net bedload sediment movement in the direction of the higher velocity flood currents may lead to sedimentation of inlets (Aubrey and Speer 1985; Fry and Aubrey 1990). Inlet channels in flood tide dominated systems can become shallower as beach sediments accumulate, decreasing channel depths and increasing the dominance of flood tides (Aubrey and Speer 1985).

The California coast experiences mixed semi-diurnal tides, i.e., two unequal high tides (Higher High Water (HHW) and Lower High Water (LHW)), and two unequal low tides (Higher Low Water (HLW) and Lower Low Water (LLW)) each day. Highest high tides and lowest low tides occur during spring tide periods (at the times of full and new moons), while less extreme tidal ranges occur during neap tides. Spring tide-neap tide cycles have a periodicity of approximately two

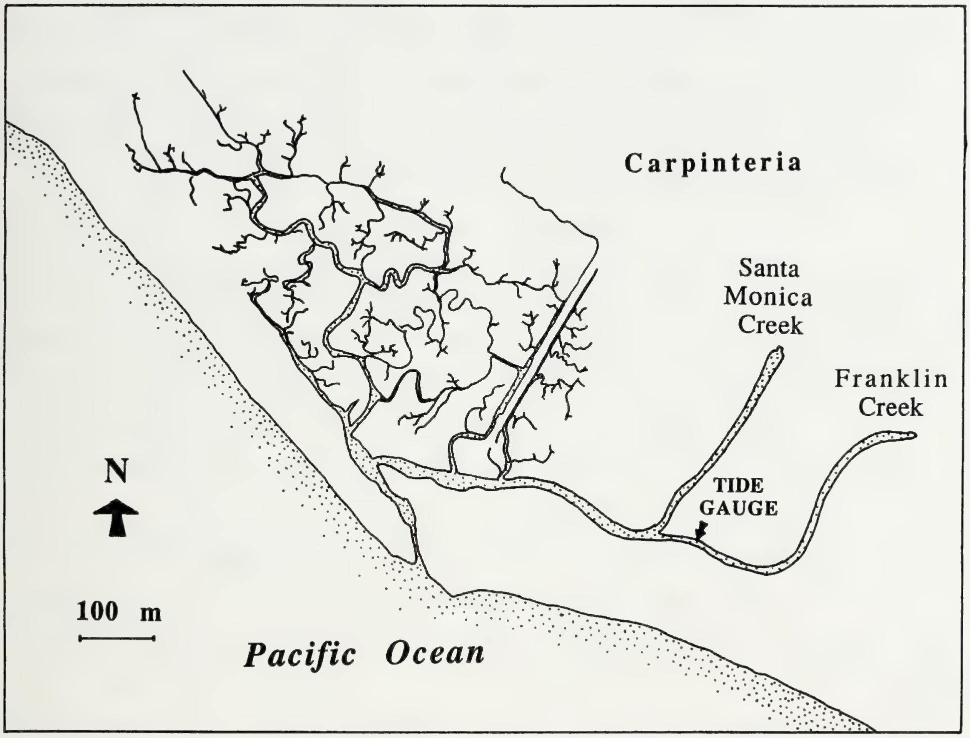

Fig. 1. Map of Carpinteria Salt Marsh, Santa Barbara County, California (34°24′N, 119°31′W).

weeks. Patterns of predicted tide heights also vary seasonally, with extreme spring tides occurring in winter and summer months, and less extreme tides occurring during the Spring and Fall.

Preliminary observations suggested that low tides in Carpinteria Salt Marsh (CSM) were up to a meter higher and several hours later than predicted tides. In this study, I examine differences between the heights and times of tides in CSM and those of predicted ocean tides and also examine the effects of rainfall and impoundment events on water levels in CSM using predicted ocean tides and tide gauge data.

Study Site

Carpinteria Salt Marsh, (34°24′N, 119°31′W, 19 km east of Santa Barbara, California, Fig. 1) consists of 93 ha of emergent wetlands, non-vegetated mud flats, shallow branching tidal channels, and channelized portions of Santa Monica Creek and Franklin Creek (Ferren 1985). There is no deepwater habitat in CSM. Pickleweed, (*Salicornia virginica* L.), is the dominant marsh vegetation (Ferren 1985; Callaway et al. 1990). The marsh is connected to the ocean by a single inlet which was stabilized by the installation of stone revetments in 1966. Since then, tidal exchange has kept the inlet open most of the time (Macdonald 1976; Ferren 1985). Although the lower surfaces of the main tidal channels at CSM were below Mean Lower Low Water (MLLW) during the study period, a sill composed of cobbles was exposed in the inlet at water levels close to Mean Sea Level (MSL).

Fresh water enters CSM as seasonal runoff from Santa Monica Creek, Franklin Creek, and several other drainages in the western portion of the marsh, and through ground water flow. Freshwater flow into the marsh is generally small compared to tidal exchange (Page et al. 1995).

Materials and Methods

Data for this study came from tide predictions for Los Angeles Outer Harbor (National Oceanic and Atmospheric Administration 1984), and strip chart recordings from the tide gauge in CSM (Santa Barbara County Flood Control District).

Predicted tides were used to describe coastal tides in the region. Times of predicted tides were adjusted to predicted times for Santa Barbara by adding a 22 minute correction and recorded to the nearest 0.1 h. Tidal height data were recorded to the nearest 0.1 foot above MLLW and converted to height in meters above MLLW.

The tide gauge in CSM is located at the Sandyland Cove Road Bridge over Franklin Creek (Fig. 1), 700 m upstream of the mouth of CSM in a channelized portion of the creek. Water level data were extracted from strip chart recordings, recorded to nearest 0.1 h and nearest 0.01 foot above MSL. Surface height data were converted to heights above MLLW by adding 0.85 m (Yean and Weber 1991).

Heights and times of tidal maxima and minima were used to characterize the tidal regimes and for comparisons between predictions and observed tide levels. Data from two periods, 15 Feb to 31 Mar 1992 (Winter) and from 1 Jul to 15 Aug 1991 (Summer), were analyzed. In order to minimize the effects of factors other than the response of surface heights in CSM to tidal forcing, the two time series analyzed were chosen from strip chart recordings in which there was no evidence of mechanical problems with the tide gauge or unusual events affecting surface heights (e.g., rainfall, inlet closure). To minimize the effect of clock errors in the CSM record, time intervals between tidal maxima and minima were used to describe the timing of predicted tides and observed CSM tides.

Results

Comparisons between the CSM tide gauge records and predicted tides (Fig. 2) revealed differences in amplitude, timing and mean water level.

Tidal range.—Mean daily tidal range in CSM was less than half of predicted tidal range during the study period (Figs. 2, 3). Mean predicted daily tidal ranges were 1.69 ± 0.53 m (± values = 1 S.D., N = 46) in the summer period and 1.55 ± 0.39 m (N = 45) in the winter period. During the same periods, the mean daily CSM tidal ranges were 0.68 ± 0.20 m and 0.66 ± 0.16 m.

Reduced tidal range in CSM was primarily due to truncation of low tides (Figs. 2, 3). Mean low tide levels in CSM were 0.7 to 0.8 m higher than the mean predicted low tides during the study periods. Variation in low tide levels in CSM was greatly reduced compared to predicted tides. Mean low tide levels in CSM were 0.99 ± 0.04 m above MLLW (N = 88) in the summer period and 1.06 ± 0.05 m (N = 88) in the winter period. Mean predicted low tides during the same periods were 0.32 ± 0.38 m above MLLW and 0.22 ± 0.32 m.

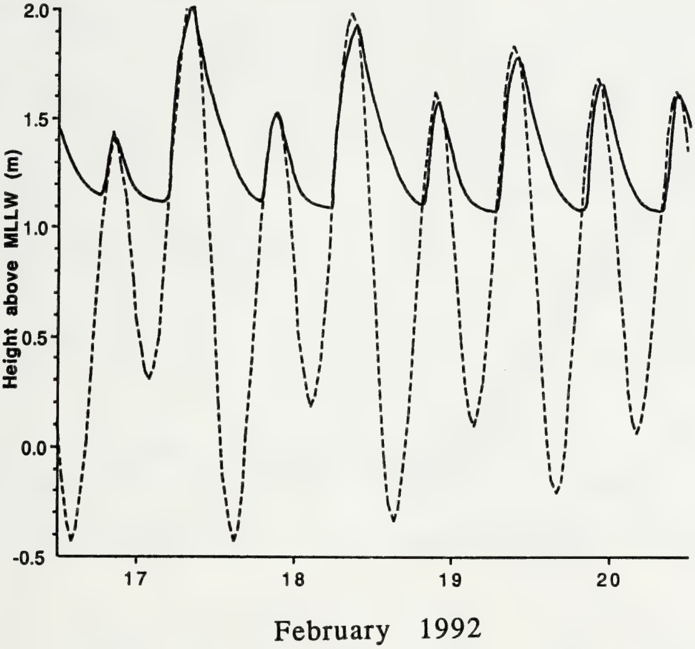

Fig. 2. Carpinteria Salt Marsh tides (solid line) and predicted tides (dotted line), 16–20 Feb 1992.

High tide levels in CSM were similar to those of predicted tides (Figs. 2, 3). Mean CSM high tides were 1.44 ± 0.30 m above MLLW (N = 88) in the summer period and 1.56 ± 0.23 m (N = 88) in the winter period. Mean predicted high tides for the same periods were 1.49 ± 0.35 m above MLLW and 1.42 ± 0.28 m.

High tide levels in CSM were positively correlated with predicted high tide levels in both periods (Fig. 4). The relationships between CSM tide heights and predicted tide heights for the two periods were not significantly different in slope ($P > 0.1$), or elevation ($P > 0.1$).

Relationships between low tide levels in CSM and predicted levels varied between the periods analyzed. No significant correlation was found between low tide levels in CSM and predicted low tide levels during the winter period (Fig. 4). A significant negative relationship was found between low tide levels in CSM and predicted low tide levels for the summer period (Fig. 4, CSM height m MLLW = −0.037 (predicted height m above MLLW) +1.01, r = 0.56, N = 88, Fig. 4). Low tides that followed spring high tides were generally the highest in the series.

The pattern of high and low tides in CSM differed from that of predicted tides (Fig. 2). The occurrence of Lower Low Water in CSM frequently corresponded with predicted HLW instead of predicted LLW. For days on which HLW and LLW were distinguishable in the predicted tide series and CSM records, LLW in CSM coincided with predicted LLW on 11 of 32, and 15 of 37 days in the summer and winter periods respectively.

In Carpinteria Salt Marsh, the lowest tide of the day generally occurred after LHW instead of after HHW (Fig. 2). During portions of the tidal series in which HHW and LLW were distinguishable, predicted LLW followed predicted HHW

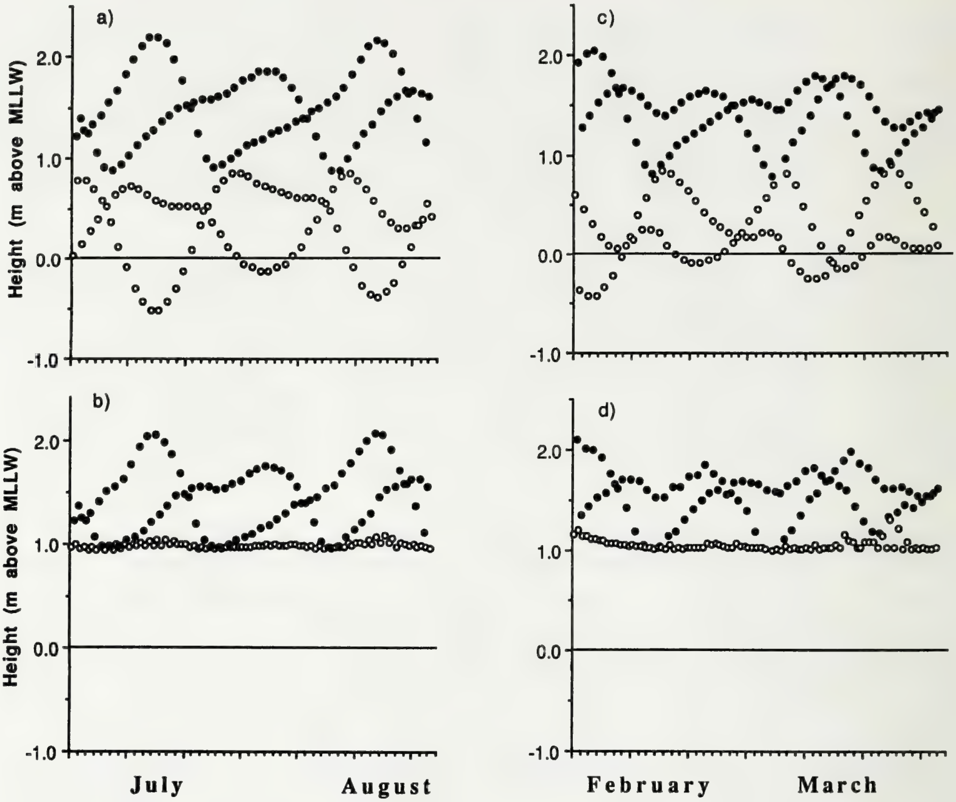

Fig. 3. a) Predicted ocean tides, and b) Carpinteria Salt Marsh tides for the period 1 Jul to 15 Aug 1991. c) Predicted ocean tides and d) Carpinteria Salt Marsh tides for the period to 15 Feb to 31 Mar 1992. High tides (solid circles), low tides (open circles).

35 of 43 times (Summer), and 42 of 45 times (Winter). For portions of the tidal series in which HHW and LLW were distinguishable, CSM LLW followed predicted HHW on 11 of 37 days, and 3 of 40 days in the same periods.

Tidal asymmetry.—Asymmetrical tides with rapid flood and extended ebb phases occurred in CSM during the study (Fig. 2). Periods of ebb flow were usually longer than the intervals for predicted tides, and flood tide intervals were correspondingly shorter (Fig. 5). Time intervals between CSM tides varied significantly with the height of the previous predicted tide (Fig. 5).

Rainfall and impoundment events.—Rainfall and impoundment events both had measurable effects on water levels in CSM. Rainfall and runoff on 11–14 Feb 1992 caused water levels in CSM to rise as much as 0.6 m in irregular peaks of

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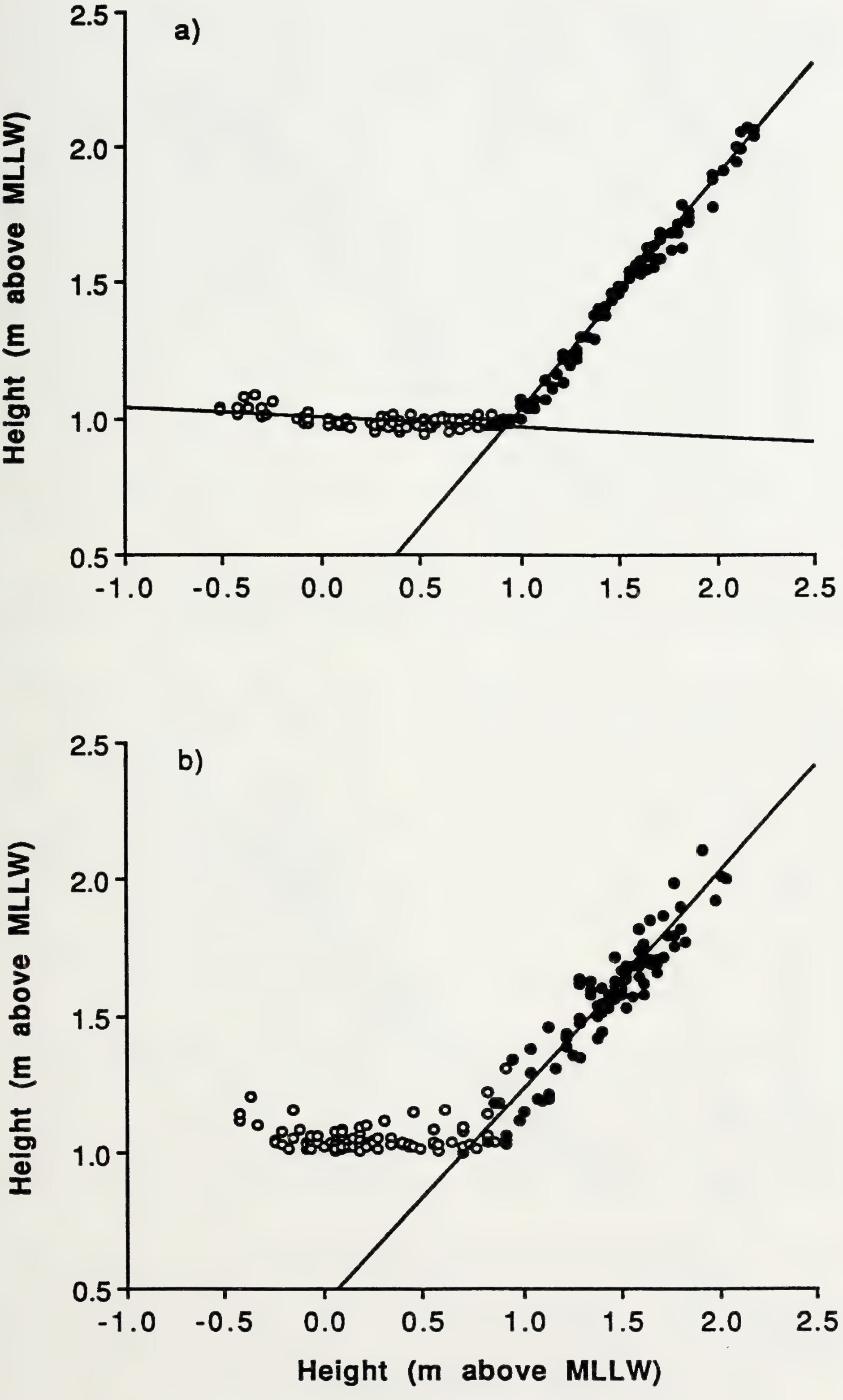
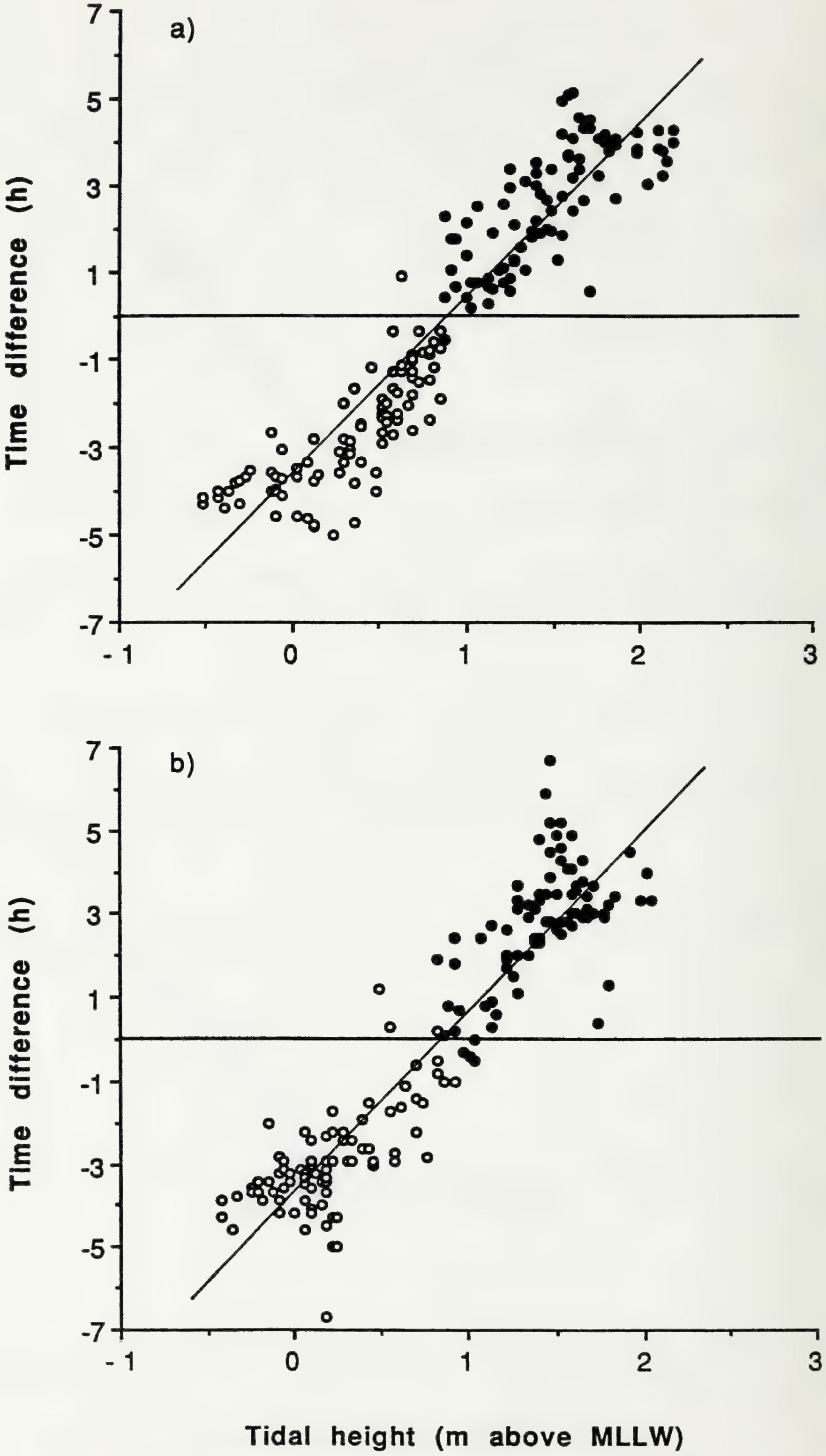
Fig. 4. Carpinteria Salt Marsh high tides (solid circles) and low tides (open circles) as functions of predicted high and low tides, a) 1 Jul to 15 Aug 1991 (CSM high tide level (m above MLLW) = predicted level × 0.79 + 0.43, r = 0.94, N = 88), b) 15 Feb to 31 Mar 1992 (CSM low tide level (m above MLLW) = predicted level × −0.04 + 1.01, r = 0.56, N = 88, and CSM high tide level (m above MLLW) = predicted level × 0.86 + 0.17, r = 0.99, N = 88).


a)
Height (m above MLLW)
2.5
2.0
1.5
1.0
0.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
b)
Height (m above MLLW)
2.5
2.0
1.5
1.0
0.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Height (m above MLLW)


a)
b)
Time difference (h)
7
5
3
1
-1
-3
-5
-7
- 1
0
1
2
3
Tidal height (m above MLLW)

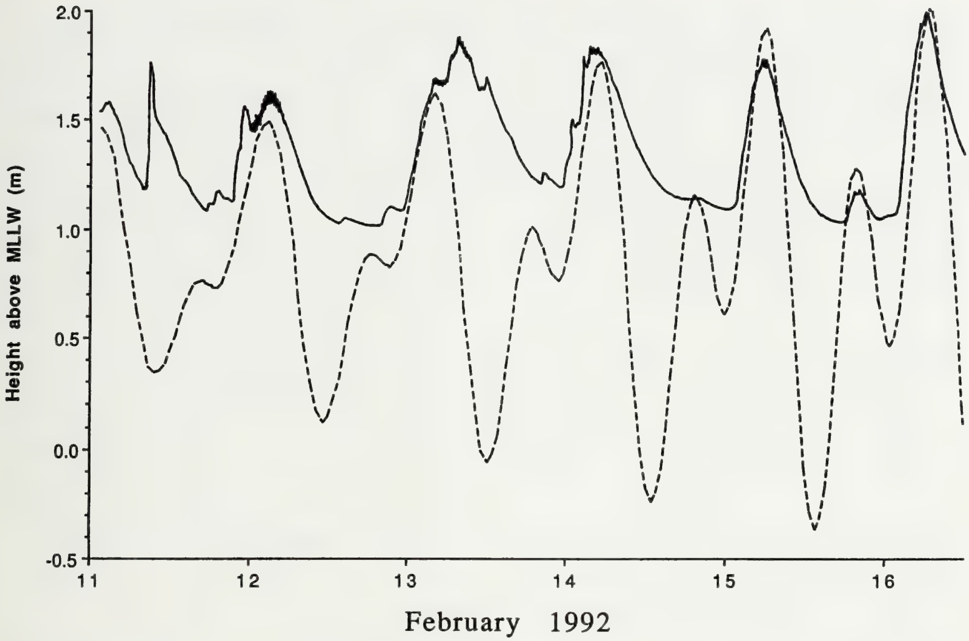


Fig. 6. Surface height (solid line) at Carpinteria Salt Marsh tide gauge and predicted ocean tides (dotted line) from 11–16 Feb 1992 including a period with heavy rainfall and runoff, 11–14 Feb 1992.

short duration (Fig. 6), and a smaller amount above their usual heights for several days. The gradual drop in the height of low tides for several days after 15 Feb 1992 (Fig. 3) may be due to diminishing fresh water runoff generated by rainfall events in the previous week.

Tidal exchange between the ocean and CSM is occasionally cut off when a sand berm builds up across the inlet. The impoundment of CSM during 22–25 Apr 1992 (Fig. 7) caused stepwise increases in surface heights over a period of days with increasing HHW tides, with slight increases in level between high tides apparently due to groundwater and surface flow, and followed by a return to tidal exchange when the berm was breached.

Discussion

Tides in CSM were strongly distorted during both study periods: tidal amplitudes were less than half of predicted amplitudes, mean water level was elevated, ebb and flood tides were asymmetrical, and the pattern of occurrence of LLW and HLW was altered. The observed response of water level in CSM to tidal forcing was consistent with the behavior of flood-dominated tidal systems described by Aubrey and Speer (1985) and Speer and Aubrey (1985). The tidal

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Fig. 5. Difference between predicted time intervals and Carpinteria Salt Marsh intervals as a function of predicted tide level, a) 1 Jul to 15 Aug 1991 (CSM time difference (h) = predicted interval × 4.03 − 3.69, N = 176), b) 15 Feb to 31 Mar 1992 (CSM time difference (h) = predicted interval × 4.29 − 3.56, N = 176). High tides (solid circles), low tides (open circles).

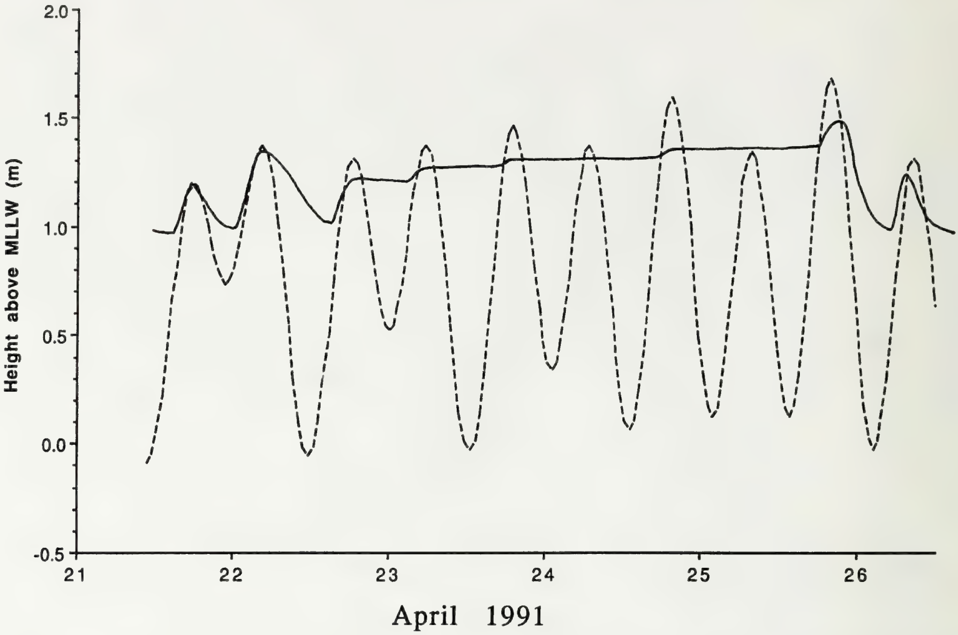

Fig. 7. Surface height (solid line) at Carpinteria Salt Marsh tide gauge and predicted ocean tides (dotted line) 21–26 Apr 1991, including an impoundment event from 22–25 Apr.

amplitude to channel depth ratio at the inlet of CSM was greater than 1.0 during the study period, substantially above the threshold value (0.3) for flood tide dominated systems (Aubrey and Speer 1985).

A cobble sill in the inlet prevented the water levels in CSM from dropping to levels lower than about 1 m above MLLW. Sills at approximately MSL have been reported in other coastal wetlands in California: at the inlet to Mugu Lagoon (MacGinitie and MacGinitie 1969; Onuf 1987), and in Elkhorn Slough (MacGinitie and MacGinitie 1969).

The negative relationship observed between heights of low tides in CSM and predicted tides in the summer period may be evidence of the generation of fortnightly tides in CSM. Mean water level in flood tide dominated systems may be higher than mean sea level due to frictional effects of channels and basins on tidal forcing (Hill 1994). Mean water levels of shallow systems may also show fortnightly variation, rising during spring tides and falling through neap periods (Hill 1994).

In 10 of 12 systems investigated by Friedrichs and Aubrey (1988), tidal distortion increased with distance from the inlet. The tide gauge in CSM is 700 m from the inlet. Locations upchannel from the tide gauge in CSM may experience stronger tidal distortion than at the tide gauge. Areas of the marsh furthest from the inlet may be beyond the reach of some high tides and may experience diurnal rather than semidiurnal tides.

Many factors can modify the influence of tidal forcing on sea levels. Low frequency phenomena that could influence water levels in CSM include seasonal variation in sea level of approximately 0.1 m in southern California (Emery and Aubrey 1991), and increases in sea level of up to 0.1 m associated with El Niño events in the region (Emery and Aubrey 1991). Shorter term influences, including wave set up of 1 m or more in the surf zone, and variations in atmospheric pressure, wind strength and direction, and runoff can also cause variations in surface height in coastal waters (Emery and Aubrey 1991). Water levels in CSM were elevated by as much as 0.6 m within a few hours of a rainfall event in the watershed and remained elevated for several days; areas above the usual range of tidal influence were inundated with water during this period. Impoundment events have been rare in CSM since stabilization of the inlet but have the potential to cause significant changes in invertebrate and fish communities (Nordby and Zedler 1991).

Tidal distortion in CSM and other shallow systems may alter environmental conditions in the intertidal by changing the daily pattern of emergence of habitat. Extreme low ocean tides typically occur before dawn in Summer and in the late afternoon in Winter in southern California. The lowest levels exposed by tides in CSM may be exposed to more extreme temperatures than the lowest levels exposed in systems with unmodified tides.

Seasonal and interannual variation in rainfall and stream flow and episodic interruption of tidal exchange have significant effects on the physical and biological functions of southern California coastal wetlands (Nordby and Zedler 1991). Changes in species richness, abundance, and population structures of invertebrates in Tijuana Estuary and Los Penasquitos Lagoon were associated with reductions in salinity and impoundment events (Nordby and Zedler 1991).

Relative to a coastal wetland experiencing unmodified ocean tides, CSM has reduced tidal range, tidal prism, turnover rate of water in the intertidal zone and area of intertidal habitat. Management of southern California's shallow tidal systems needs to account for the effects of tidal distortion as tidal exchange and sediment transport may vary considerably from models based on predicted ocean tides.

Acknowledgements

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Fossil Remains of the Legless Lizard, *Anniella* Gray, 1852 from Late Pleistocene Deposits at Rancho La Brea, California

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A recent search through fossil vertebrate remains recovered from the famous tar seep deposits at Rancho La Brea in the Los Angeles County Museum collections at the Page Museum in Los Angeles, California resulted in the discovery of two small vertebrae (LACMRLP 52246, 52248) belonging to the anguimorph lizard *Anniella.* This genus is represented by two extant species (the controversy over the nomenclatural arrangement within the genus was resolved by designation of a neotype; see Hunt 1983; Murphy and Smith 1991; International Commission on Zoological Nomenclature 1993). *Anniella pulchra* Gray ranges from the San Francisco Bay area of California into Baja California Norte, Mexico, and is found on Los Coronados and Todos Santos islands off the Pacific coast of Baja California. *Anniella geronimensis* Shaw was originally described from San Geronimo Island off the Pacific coast of Baja California Norte, Mexico, and also inhabits a relatively narrow strip of land along the Pacific side of the Baja California peninsula. The two species live in sympatry along a narrow section of the coast of Baja California Norte (Shaw 1940, 1953; Bezy et al. 1977; Wilcox 1980).

Until recently, fossil specimens of *Anniella* were very rare. The first fossil material of the genus was reported from Clarendonian age sediments in Bolinger Canyon, California and consists of poorly preserved vertebral fragments (Gauthier 1980). Early Pleistocene fossils from sediments in the Elsinore Fault Zone, Riverside Co., California were reported by Reynolds et al. (1990, 1991) and Bell (1993). Recent paleontological salvage projects in southern and central California have produced numerous specimens of *Anniella* from 18 additional Pliocene and Pleistocene localities (Bell et al. 1995).

The *Anniella* material from Rancho La Brea consists of two isolated vertebrae recovered from the Pit 91 locality (LACM 6909). This locality is situated over one of the original 1915 pits that was abandoned prior to the completion of the excavation; the exact position within Hancock Park is recorded by Marcus (1960). Excavations at Pit 91 began again in 1969 and utilized a one-yard-square grid system, with special attention paid to stratigraphic control and the recovery of smaller specimens (see Shaw 1982 for details). The two vertebrae reported here were recovered from grid GJM 550/M-3, at a depth of 2.13–2.29 m below datum (datum is 52.4 m above mean sea level). The sediments from this grid and level were described by Whistler (1989), and are associated with a ^{14}C radiometric date of 32,600 ± 2800 radiocarbon years before present (Marcus and Berger 1984; Whistler 1989). This is the first time that fossil *Anniella* material has been associated with a radiometric date.

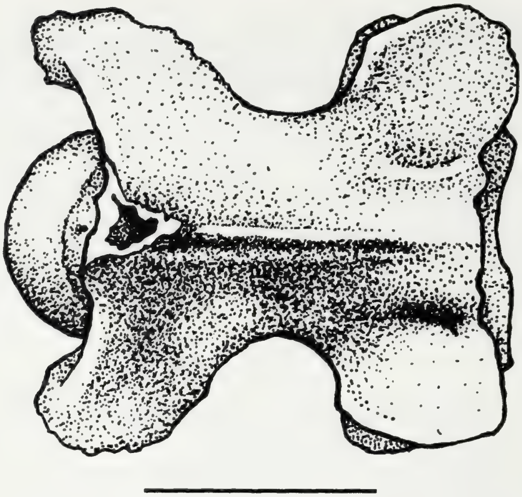

Fig. 1. Dorsal view of anterior trunk vertebra of *Anniella* sp. (LACMRLP 52246) from Rancho La Brea, California. Anterior is to right. Scale bar = 1 mm.

The horizontally eliptical outline and oblique orientation of the cotyles and condyles, and the lack of subcentral ridges or grooves on the vertebrae indicate their anguimorphan affinity (Hoffstetter and Gasc 1969; Gauthier 1980). The vertebral centra of *Anniella* and limbless members of the Anguinae (e.g., *Anguis*) are elongate, have flat ventral surfaces, are equal in width to the condyle and are roughly parallel-sided for much of their length (Gauthier 1980). In other members of the Anguidae there is a low, blunt ridge on the ventral surface of the centrum and the lateral borders of the centrum diverge from the condyle to the cotyle, forming a roughly triangular outline in ventral view (Hoffstetter and Gasc 1969). *Anniella* is the smallest anguimorph lizard known, and the small size of these fossil specimens indicates their affinities with that genus. At this time, isolated vertebrae of *Anniella* are not identifiable to species (Bell et al. 1995).

LACMRLP 52246 has a subquadrate shape when viewed in dorsal aspect (Fig. 1), but lacks any trace of a hypapophysis on the ventral surface. This morphology is typical of the anterior trunk vertebrae; the 9 or 10 vertebrae that follow the cervicals in *Anniella* (as discussed by Bell et al. 1995). LACMRLP 52248 has a rectangular shape when viewed in dorsal aspect and has a flat ventral surface with no hypapophysis; this morphology is typical of the majority of vertebrae in *Anniella* and apart from stating that it is posterior to the anterior trunk vertebrae and anterior to the ultimate trunk vertebra (Bell et al. 1995), the specimen cannot be reliably placed within the the vertebral column.

Despite decades of research and excavation at Rancho La Brea, and numerous fossils recovered from the various localities (Stock and Harris 1992), the amphibian and reptile remains have received relatively little attention (Table 1). The earliest report on herpetofaunal remains was limited to a discussion of anurans (Camp 1917), and a more detailed picture did not emerge until Brattstrom's (1953, 1958) reports summarizing the reptile and amphibian taxa known at the time. Over two decades passed before a detailed study of the ophidian fauna became available (LaDuke 1983; 1991a). More recently, the first reports of tortoise and

Table 1. List of amphibian and non-avian reptile taxa reported from Pleistocene and Holocene deposits at Rancho La Brea, California (data modified from Brattstrom 1953, 1958; Fay 1991; LaDuke 1991a, b; Stock and Harris 1992; Tihen 1962).

- Amphibia
  - Caudata
    - Plethodontidae
      - *Aneides lugubris*
  - Anura
    - Bufonidae
      - *B. boreas*
      - *B. microscaphus*
    - Hylidae
      - *Hyla* sp.
    - Ranidae
      - *Rana aurora*
- Reptilia
  - Testudines
    - Emydidae
      - *Clemmys marmorata*
    - Testudinidae
      - gen. and sp. indet.
  - Squamata
    - Phrynosomatidae
      - *Phrynosoma coronatum*
      - *Sceloporus magister*
      - *S. occidentalis*
      - *Uta stansburiana*
    - Scincidae
      - *Eumeces skiltonianus*
    - Teiidae
      - *Cnemidophorus tigris*
    - Anniellidae
      - *Anniella* sp.
    - Anguidae
      - *Elgaria multicarinata*
    - Colubridae
      - *Arizona elegans*
      - *Coluber constrictor*
      - *Diadophis punctatus*
      - *Hypsiglena torquata*
      - *Lampropeltis getulus*
      - *Lampropeltis* sp.
      - *Masticophis lateralis*
      - *Pituophis melanoleucus*
      - *Rhinocheilus lecontei*
      - *Tantilla* sp.
      - *Thamnophis* cf. *T. couchi*
      - *T. sirtalis*
      - *Thamnophis* sp.
    - Viperidae
      - *Crotalus viridis*
      - *Crotalus* sp.

salamander remains and a brief discussion of additional lizard specimens have appeared (Fay 1991; LaDuke 1991b; Bell and Dundas 1993). The specimens of *Anniella* reported here represent a new taxon for the Rancho La Brea fauna, and mark the promise of future discoveries to be made in the herpetofaunal community from Rancho La Brea.

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An abstract summarizing in concise terms the methods, findings, and implications discussed in the paper *must* accompany a *feature article. Abstract should not exceed 100 words.*

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The literature cited: Entries for books and articles should take these forms.

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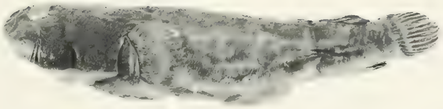

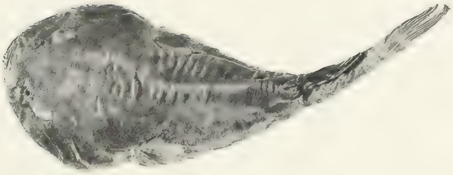

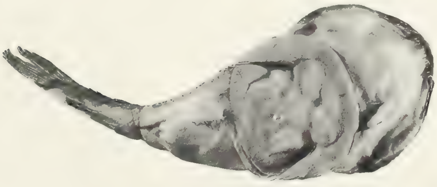

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MICROBIAL ACTIVITY IN THE DIGESTIVE TRACT OF THE HALFMOON, ***Medialuna californiensis.*** J. S. Kandel[1], J. R. Paterek[2] and M. H. Horn[1], [1]California State Univ. Fullerton. CA 92634 and [2]Agouron Institute, La Jolla, CA 92037.

We report the presence of a diverse microbial flora and of microbial fermentation products in the hindgut region of the halfmoon, ***Medialuna californiensis,*** a seaweed-eating fish from southern California coastal waters. Viable aerobic and anaerobic bacteria were found in all sections of the gut, but were of highest concentration (10^5–10^8/ml) in the hindgut. Microscopy revealed vibrios, spirilla, rod-shaped bacteria and flagellated protozoa in the midgut and hindgut, but primarily vibrios and rods in the stomach and foregut. Acetic, isobutyric and butyric acids, the volatile products of microbial breakdown of carbohydrates, were found only in the hindgut, as was ethanol, a nonvolatile product. These results provide the first evidence for microbial fermentation and its possible contribution to the energy supply in a north-temperate herbivorous fish.

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Postfire Vegetation Recovery in the Santa Monica Mountains Under Two Alternative Management Programs

Jon E. Keeley

Department of Biology, Occidental College, Los Angeles, California 90041

Abstract.—In the autumn of 1993, two large wildfires were ignited within a week of each other at opposite ends of the Santa Monica Mountains. This study compared postfire plant recovery on the Green Meadow burn, which was managed passively by relying solely on natural regeneration, with recovery on the Old Topanga burn, which was actively managed by aerial seeding of mostly non-native annual grasses and forbs. Establishment of both exotic and native seeded species was very poor and largely insignificant, relative to the natural regeneration. Comparing recovery on the Old Topanga burn and Green Meadow burn, there was no significant difference in plant cover on the two burns. Aerial seeding did contribute to a significantly greater number of non-native species on the Old Topanga burn, but it is unknown whether or not seeding contributed to the reduced species richness observed on the Old Topanga sites.

Over a period of less than 10 days in autumn 1993, the southern California landscape exploded in massive wildfires that burned more than 80,000 ha (Anonymous 1993a). These fires were particularly important because they touched off a storm of controversy that had far reaching political ramifications. Much of the controversy stemmed from the fact that many fires burned simultaneously on lands under the jurisdiction of different agencies which advocated different postfire management practices.

One situation, exploited by the media, was the coincidence of massive wildfires in both the western and eastern ends of the Santa Monica Mountains. The Green Meadow Fire burned over 16,000 ha of state and national park land at the western end of the range, including much of Pt. Mugu State Park. Days later the Old Topanga Fire burned nearly 7000 ha of Los Angeles County and other smaller holdings at the eastern end, between Malibu and Old Topanga Canyon Rd. Almost within days of the Old Topanga Fire, the County of Los Angeles announced that, as an erosion control measure, they would seed lands under their jurisdiction, at a cost of $440,000 (Anonymous 1993b; Keeley et al. 1995). In marked contrast, both the state and national parks announced that seeding was neither necessary nor desirable and, not only would they not seed their lands burned by the Green Meadow Fire, they requested that the County of Los Angeles take care to avoid seeding the small pockets of park land within the Old Topanga Fire. Although the Los Angeles County Forestry Division announced that native species would be utilized, only 3% of the seed mix comprised native species, specifically *Bromus carinatus* (Table 1).

The purpose of this study was to monitor postfire recovery on sites that received aerial seeding within the perimeter of the Old Topanga Fire and on sites not seeded within the perimeter of the Green Meadow Fire. I am testing the hypothesis that

Table 1. Seedling prescription used to aerial seed the Los Angeles County and City of Malibu lands burned by the Old Topanga Fire. Seeding was done in late November 1993. Data were provided by the Santa Monica Mountains National Recreation Area, 18 August 1994. *Bromus carinatus* is a native species, others are not native to California (Hickman 1993).

	Percentage			
	By mass	Numerically@		
Trifolium hirtum (rose clover)	49	22	Seeding density	= 5.4 kg/ha (4.8 lbs/ac)
Vulpia myuros (zorro fescue)	26	56	Area seeded	= 5041 ha (12,456 ac)
Bromus carinatus (California brome)	13	3	Seed cost	= $393,500
Bromus hordeaceous (blando brome)	12	19	Total cost*	= $87/ha ($35/ac)

@ Based on average number of seeds per kg (from Ransom Seed Lab, unpublished data).

* Total cost includes application costs.

aerial seeding of burned slopes increases postfire plant cover over sites recovering naturally.

Study Sites

The primary criteria for site selection were accessibility and lack of other disturbances. Since site characteristics such as slope aspect, inclination, rock cover, soil nutrients, prefire vegetation age and fire intensity can affect vegetative recovery, sites comparable in these respects were selected from both seeded and non-seeded areas. Sites within the Old Topanga Fire were selected from within seeded areas indicated on a map provided by the Los Angeles County Fire Department, Division of Forestry. Ten sites were selected across the extent of the Old Topanga Fire; three at the northern end off Old Topanga Canyon Rd., three near the eastern end in Tuna Canyon, two near the western end in Puerco Canyon, one at the mouth of Carbon Canyon and one in the center of the burn off Schueren Rd.

For the area burned by the Green Meadow Fire and not aerially seeded, ten sites were selected within Pt. Mugu State Park (five in upper Big Sycamore Canyon, five in lower Big Sycamore Canyon), and two additional sites near Circle X Ranch were included.

In the first growing season after the fire, rainfall was slightly below average. Precipitation during the four months of November, December, January, and February, which was between the time of the fire and the first sampling period, was 79% of the long term average for the nearest climatological station at Oxnard (NOAA, Climatological data for California, 1993–1994). The following three months (March, April and May), between the first and second sampling periods, was 90% of the average.

Methods

Each site was 1000 m^2, subdivided into ten plots of 100 m^2 each, in which prefire and postfire shrub composition was determined, and within each of the ten plots, two 1 m^2 subplots were selected and total herb and shrub density was recorded. Also, in each of the 1 m^2 subplots, aerial diameter and height were recorded for three individuals of every species, selected to represent the range of

Table 2. Site characteristics for 22 sites in the Old Topanga and Green Meadow fires.

Site	Distance from coast (km)	Elevation (m)	Aspect (°)	Inclination (°)	Insolation (KC/cm²)
Old Topanga Fire					
Carbon Cyn	1	60	SSW	28	313
Old Topanga 1	8	475	S	27	316
Old Topanga 2	8	425	W	26	262
Old Topanga 3	8	450	E	12	269
Puerco Cyn 1	1	120	E	28	262
Puerco Cyn 2	1	120	NW	23	219
Schueren Rd	4	600	SSW	19	309
Tuna Cyn 1	2	450	NNW	35	153
Tuna Cyn 2	1	350	E	28	262
Tuna Cyn 3	1	365	NNE	21	202
Green Meadow Fire					
L. Sycamore Cyn 1	2	110	S	21	312
L. Sycamore Cyn 2	2	120	NW	18	232
L. Sycamore Cyn 3	2	160	N	32	176
L. Sycamore Cyn 4	1	75	WNW	30	227
L. Sycamore Cyn 5	4	100	S	20	312
U. Sycamore Cyn 1	10	260	N	27	176
U. Sycamore Cyn 2	10	250	S	31	317
U. Sycamore Cyn 3	9	210	WNW	28	234
U. Sycamore Cyn 4	8	170	NNW	21	202
U. Sycamore Cyn 5	4	130	ESE	22	285
Circle X 1	6	730	NNW	24	184
Circle X 2	6	700	S	21	312

sizes in the subplot. Coverage was estimated by calculating the average aerial cover for the three samples of each species (assuming the canopy approximated a circle) and multiplying by the plot density for that species. Vegetation was sampled in late winter (last week of February) and again in late spring (second week of June) of 1994.

Slope aspect was measured with a compass, inclination with a clinometer. Elevation and distance from the coast were taken from topographic maps. Prefire stand age was determined from polished wood samples cut from shrub skeletons collected at each site. Total annual solar insolation was calculated from tables based on slope aspect, inclination and latitude.

Two estimates of fire intensity were made from measurements of shrub skeletal remains. Since these were not direct measures of fire intensity they were labeled "Fire Severity Indices". Index #1 was based on the diameter of the smallest twig remaining on the shrub skeleton in or nearest to each 1 m^2 subplot. The justification for using this as a surrogate measure for fire intensity is based on a study by Moreno and Oechel (1989) which related known fire intensity to diameter of the smallest twig remaining on shrub skeletons of *Adenostoma fasciculatum.* Since our study dealt with species in addition to *Adenostoma fasciculatum,* we assigned an index, between 1 and 10, to different diameter shrub skeleton twigs based on two assumptions: (1) smaller twigs reflected lower fire intensities and (2) for a

Table 3. Vegetation type, age, fire severity indices and rock cover for the 22 sites in the Old Topanga and Green Meadow fires.

Site	Pre-burn vegetation type	Pre-burn age (yrs)	Average fire severity index 1	Average fire severity index 2	Mean rock cover (%)
Old Topanga Fire					
Carbon Cyn	Coastal Sage	25	4.1	5.6	19
Old Topanga 1	Chaparral	31	4.9	7.2	11
Old Topanga 2	Chaparral	48	4.9	6.3	9
Old Topanga 3	Chaparral	55	4.3	7.2	10
Puerco Cyn 1	Coastal Sage	22	3.3	2.0	1
Puerco Cyn 2	Coastal Sage	21	2.5	4.5	5
Schueren Rd	Chaparral	25	7.5	4.9	18
Tuna Cyn 1	Coastal Sage	36	4.2	4.9	15
Tuna Cyn 2	Chaparral	24	4.8	4.9	5
Tuna Cyn 3	Chaparral	24	7.2	4.9	6
Green Meadow Fire					
L. Sycamore Cyn 1	Coastal Sage	19	4.4	6.7	21
L. Sycamore Cyn 2	Coastal Sage	20	4.5	5.5	4
L. Sycamore Cyn 3	Chaparral	21	3.0	5.5	14
L. Sycamore Cyn 4	Coastal Sage	3	1.2	4.0	3
L. Sycamore Cyn 5	Chaparral	17	6.4	7.8	30
U. Sycamore Cyn 1	Chaparral	26	9.2	4.9	5
U. Sycamore Cyn 2	Coastal Sage	26	6.2	4.9	28
U. Sycamore Cyn 3	Chaparral	6	2.1	4.9	9
U. Sycamore Cyn 4	Chaparral	31	3.9	4.9	14
U. Sycamore Cyn 5	Coastal Sage	20	3.9	4.9	24
Circle X 1	Chaparral	48	3.8	4.9	6
Circle X 2	Chaparral	35	4.5	4.9	8

given twig diameter, coastal sage shrubs would have generated a lower fire intensity than chaparral shrubs. Fire Severity Index #2 was based on the height above ground level of shrub skeleton. Within each of the ten 100 m^2 plots, five skeletons of each woody species were measured. As with Index #1, indices from 1 to 10 were assigned to different heights based on two assumptions: (1) shrub skeletons burned to ground level reflected higher fire intensities than skeletons still standing, i.e., shorter skeletons reflected a higher fire intensity than taller skeletons, and (2) for a given skeleton height, coastal sage shrubs would have generated a lower fire intensity than chaparral shrubs. Although it is expected that stand age would affect this index, insufficient understanding of this relationship precluded using age in this index.

At each site, rock cover (as a percentage of ground surface covered) was visually estimated in each 1 m^2 subplot. Soil nutrient analyses were performed by the soil testing lab in the USDA Forest Service, Riverside Fire Lab on three samples collected in early spring from each site.

Pairwise comparisons were made with either a one-tailed or two-tailed t-test, as appropriate. Correlations were with the Pearson product moment correlation coefficient.

Table 4. Average soil characteristics for the 22 sites in the Old Topanga and Green Meadow fires (N = 3).

	Soil characteristics					
Site	pH	Sand (%)	Clay (%)	P (%)	N (%)	C (%)
Old Topanga Fire						
Carbon Cyn	6.3	59	10	0.05	0.30	4.9
Old Topanga 1	6.6	56	18	0.06	0.16	2.2
Old Topanga 2	6.8	33	28	0.05	0.16	2.5
Old Topanga 3	6.3	62	16	0.04	0.15	2.3
Puerco Cyn 1	6.6	47	34	0.07	0.26	2.8
Puerco Cyn 2	6.5	38	39	0.06	0.29	3.5
Schueren Rd	6.5	61	13	0.06	0.32	4.4
Tuna Cyn 1	6.5	68	11	0.05	0.33	5.2
Tuna Cyn 2	6.5	67	12	0.05	0.33	5.0
Tuna Cyn 3	6.4	54	19	0.04	0.30	4.4
Green Meadow Fire						
L. Sycamore Cyn 1	6.5	59	15	0.09	0.29	3.5
L. Sycamore Cyn 2	6.4	58	13	0.08	0.32	3.9
L. Sycamore Cyn 3	6.8	64	14	0.03	0.15	2.5
L. Sycamore Cyn 4	7.0	53	25	0.04	0.21	2.7
L. Sycamore Cyn 5	6.8	57	16	0.05	0.42	7.8
U. Sycamore Cyn 1	7.1	56	12	0.04	0.38	6.4
U. Sycamore Cyn 2	6.6	58	16	0.07	0.18	2.7
U. Sycamore Cyn 3	6.3	49	19	0.06	0.49	8.1
U. Sycamore Cyn 4	6.1	60	15	0.06	0.37	5.3
U. Sycamore Cyn 5	6.2	58	15	0.05	0.27	3.0
Circle X 1	6.8	54	20	0.06	0.43	7.3
Circle X 2	6.6	58	14	0.08	0.48	6.6

Results and Discussion

Site Characteristics

A summary of the site characteristics is given in Tables 2, 3, & 4. The 10 sites aerially seeded within the perimeter of the Old Topanga Fire were generally similar to the 12 sites not seeded within the perimeter of the Green Meadow Fire. Both seeded and non-seeded sites included ones near the coast and ones 8–10 km further inland; sites near sea-level and above 600 m; sites on all major slope aspects and sites with a similar range of inclines.

In each burn, approximately half of the sites were in coastal sage scrub and half in chaparral. Prefire stand ages were mostly between 20–30 yrs but the range was from 3 to 55 yrs; mean was 31 yrs for the Old Topanga Fire and 27 yrs for the Green Meadow Fire. Based on the two measures of fire severity, apparently there were sites in each burn that were more intensely burned than others. Other characteristics such as rock cover and soil characteristics were generally similar between sites in the two burns (Tables 3 and 4). Using a 2-tailed t-test, there was no significant difference ($P > 0.05$) between Old Topanga sites and Green Meadow sites for the site characteristics specified in Tables 2–4.

Thus, site characteristics between seeded and non-seeded sites were broadly similar.

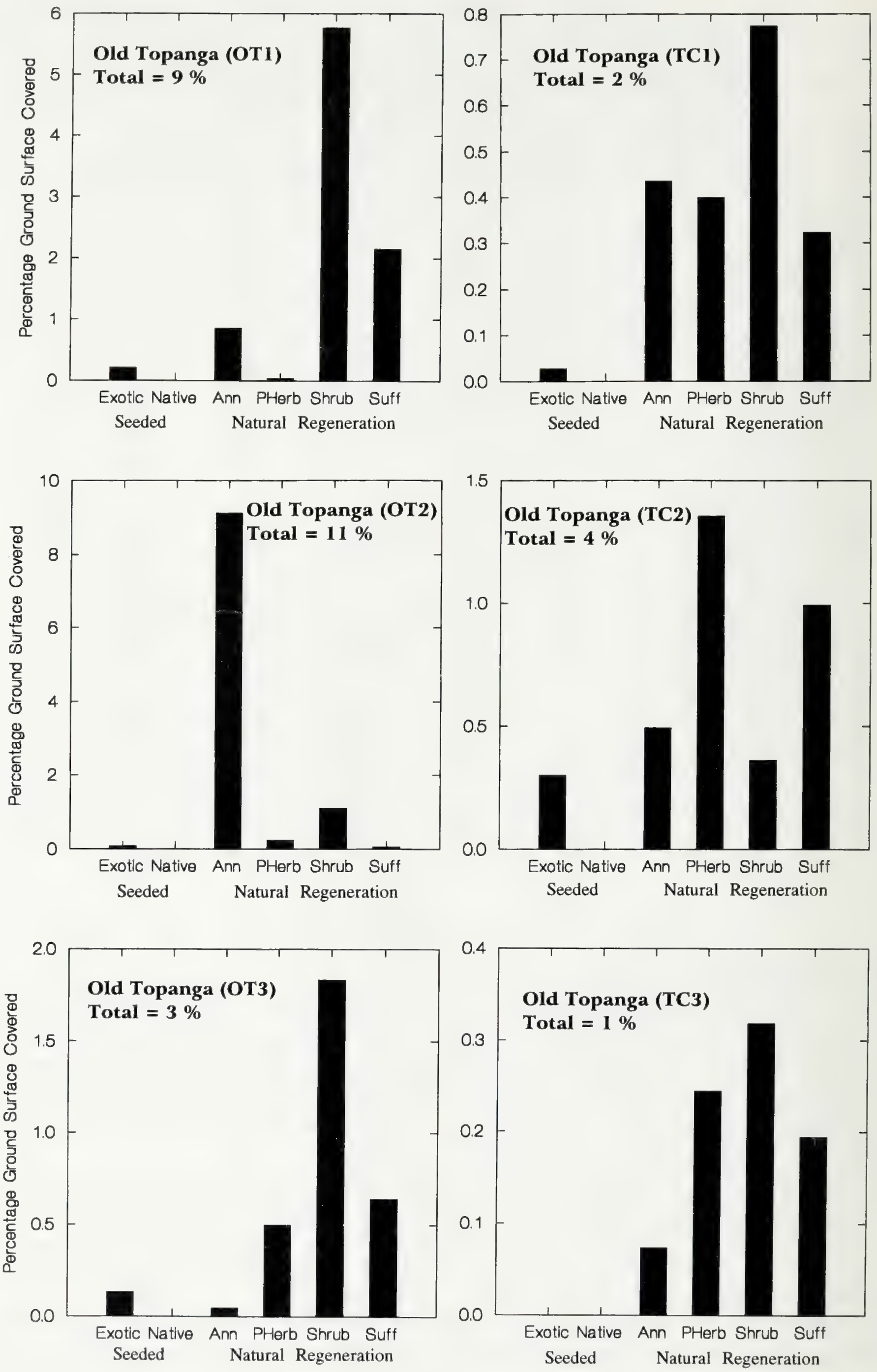

Fig. 1. Percentage ground surface covered for seeded species (non-native exotic species and native species) and for natural regeneration (annuals, herbaceous perennials, shrubs and suffrutescents; suffrutescents are species that become woody only near the base) as of 1 March 1994 for each of the 10 seeded sites in the Old Topanga burn.

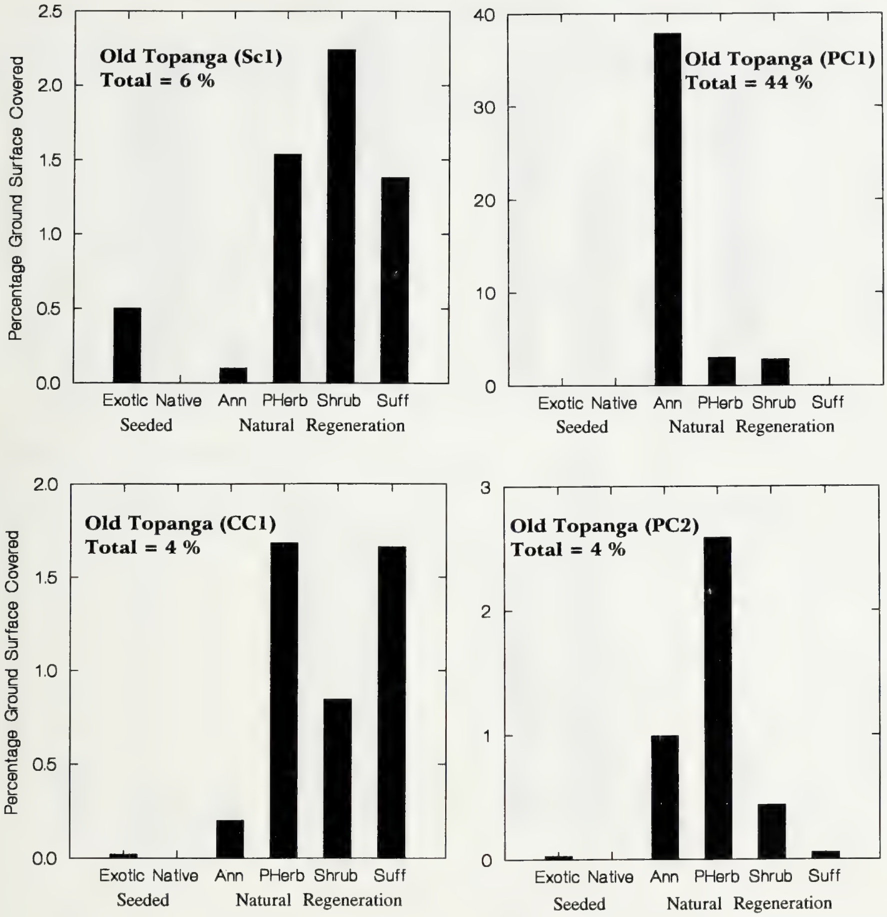

Fig. 1. Continued.

Winter Vegetation Recovery on Seeded Sites in the Old Topanga Burn

Vegetation recovery by the end of the winter storm season, approximately three months after the aerial seeding, is presented by site in Figure 1. Total cover ranged from 1% to 44% ground surface covered, however, cover contributed by seeded species ranged from 0–0.5%. Lack of establishment of seeded species is not due to our sites being missed by the aerial seeding effort as evidenced by the presence of the seeded species *Trifolium hirtum* and *Vulpia myuros* on all 10 Old Topanga sites, but not on any of the 12 sites from the Green Meadow burn. These two species represented the bulk of the seed mixture dropped on the Old Topanga burn (Table 1).

Close to 90 percent of the seed mixture used for aerial seeding comprised three species, *Trifolium hirtum, Vulpia myuros,* and *Bromus hordeaceous,* which are widespread annual grasses in southern California, although of European origin (Hickman 1993). The fact that these are not native to California is at odds with reports in the Los Angeles Times (Anonymous 1993b), which noted that the chief of the Los Angeles County Fire Department's Forestry Division had stated, "We

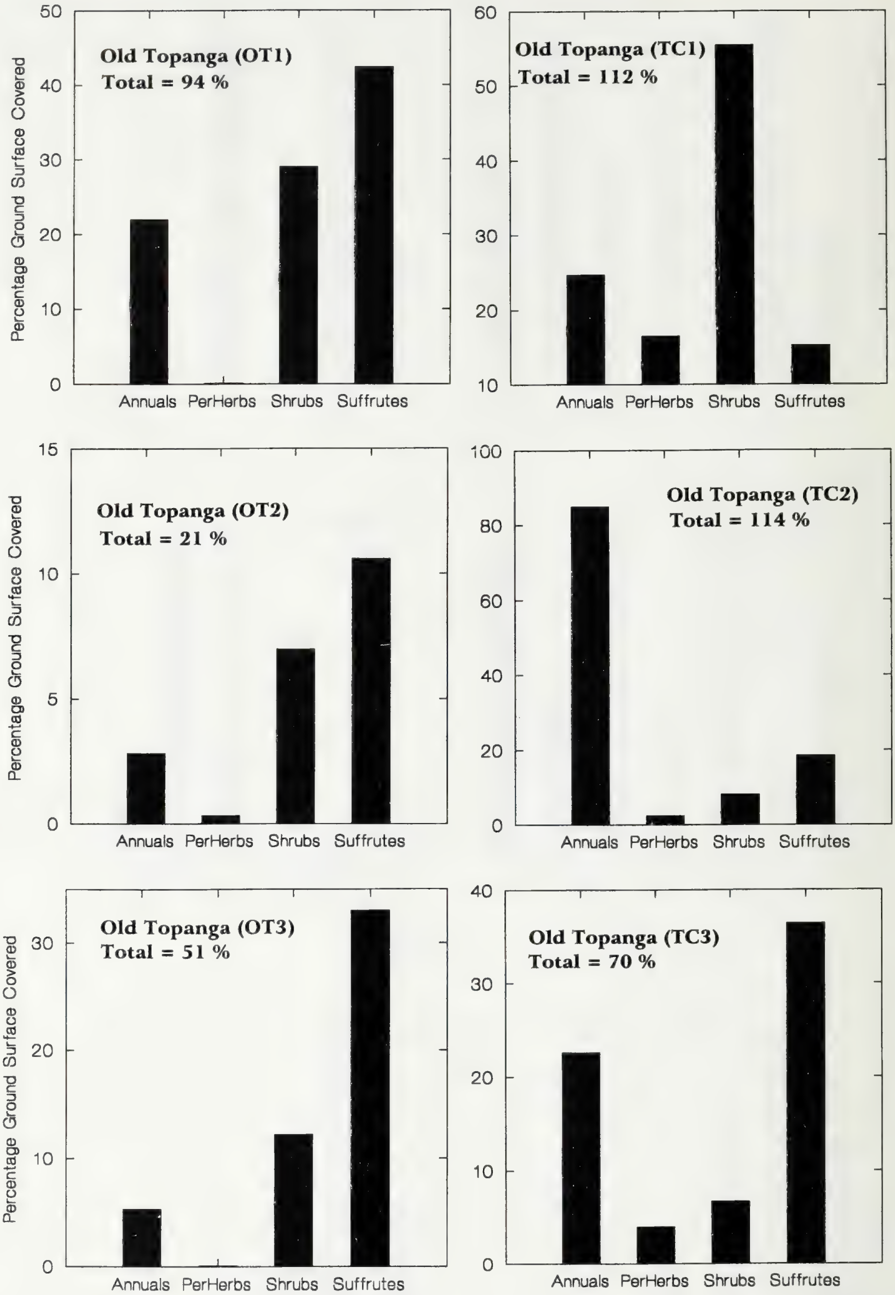

Fig. 2. Peak vegetative recovery recorded at the end of spring 1994 on the 10 Old Topanga burn sites.

can sow rye grass and make a lot of people unhappy, or we can sow native grasses and not upset a lot of people. We're trying to be sensitive to the environmentalist concerns." However, only one minor component of the seed mix (*Bromus carinatus*) is native to California. A few isolated individuals of *Bromus car-*

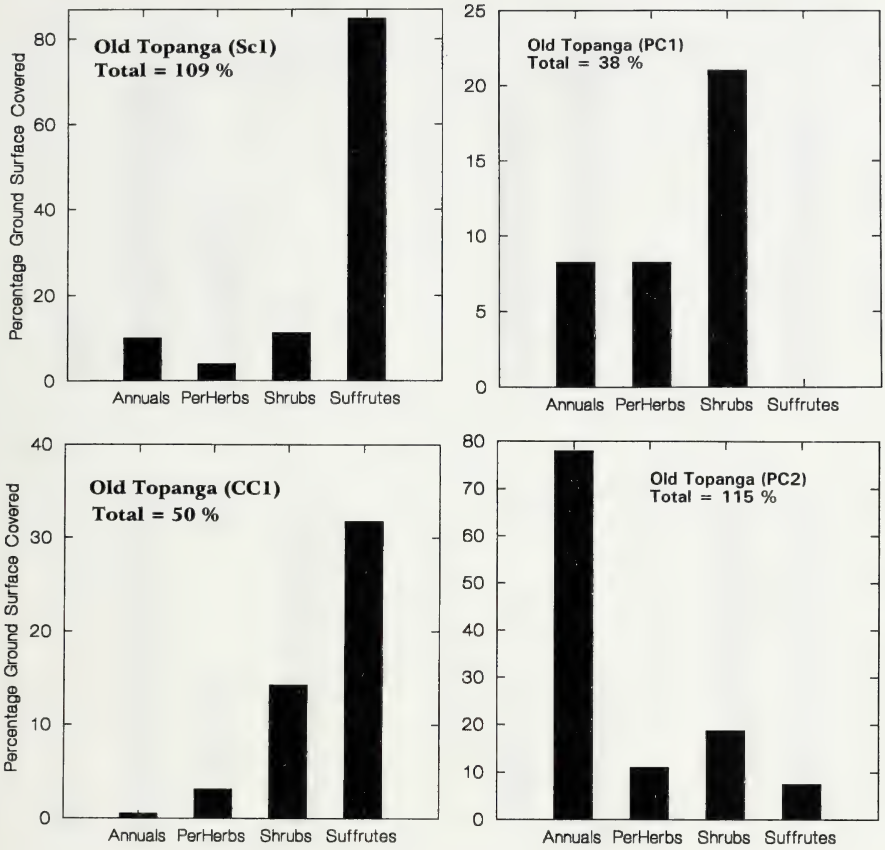

Fig. 2. Continued.

inatus were recorded from four of the Old Topanga sites and none were recorded from the Green Meadow sites. Poor establishment of this native species is likely due to two factors. (1) This species represented only a minor proportion of the seed mix (Table 1), and (2) this species is not typically found on burned sites in this region; no published postfire studies in the Santa Monica Mountains have reported *Bromus carinatus* (e.g., Radtke 1981; O'Leary 1984; Keeley and Keeley 1984; O'Leary and Westman 1988; Conard et al. 1995). Further, while some native bunchgrasses such as *Nasella lepida* are common on burned sites, their presence is due to resprouts, with seedling regeneration occurring in subsequent years on most sites (Keeley, unpublished data), suggesting that in general our native grasses may be poor choices for seed mixtures.

Very likely a contributing factor to low establishment of seeded species was the below average rainfall, which, during the months prior to sampling, was 21% below average (see Study Sites Section). Nonetheless, there was sufficient rainfall to support establishment of significant native cover on most sites (Fig. 1).

In summary, the natural regeneration far exceeded that attempted through aerial seeding; by two orders of magnitude on most sites. These sites were monitored throughout the spring growing season, and although total cover increased (see

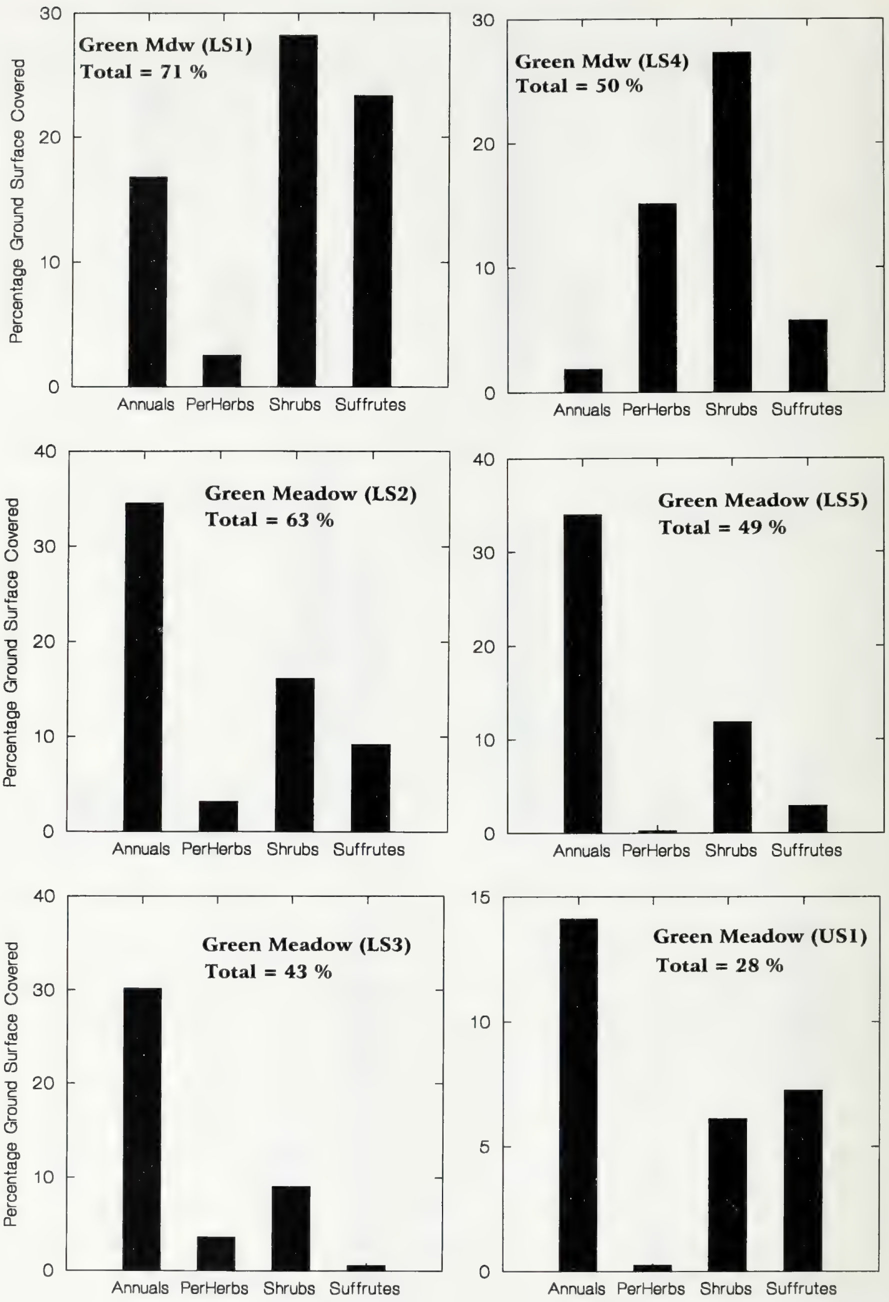

Fig. 3. Peak vegetative recovery recorded at the end of spring 1994 on the 12 Green Meadow burn sites.

below), there was little change in the relative importance of seeded species. The very poor coverage produced by seeded species during the winter months is noteworthy because further increases in coverage later in the spring are unlikely to have any significant effect on erosion and flooding. Because seeded species never

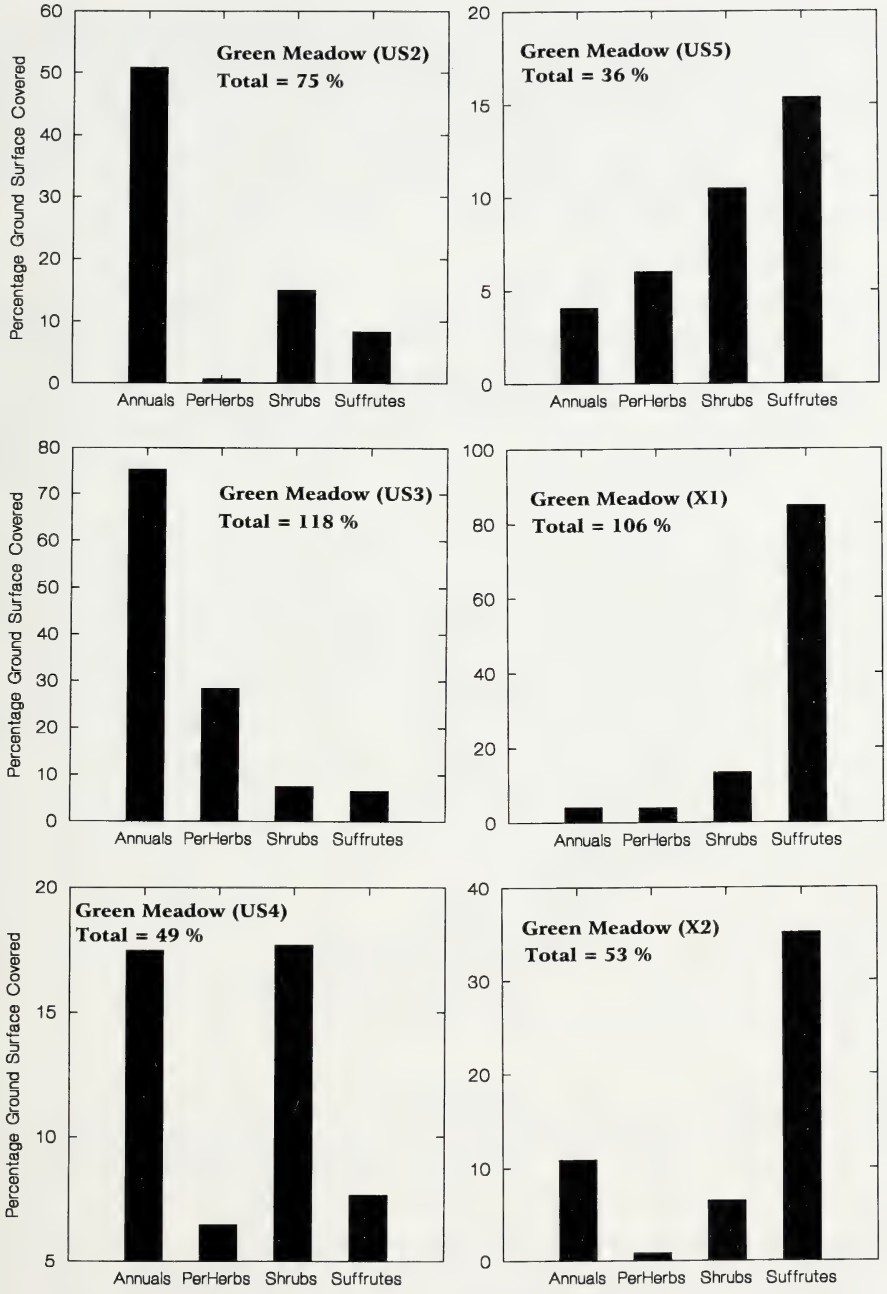

Fig. 3. Continued.

represented more than a minor fraction of the total plant cover, the $440,000 spent on aerial seeding was clearly not a good investment on this burn.

What is the prognosis for seeding in future years? It seems unlikely that the below average rainfall was a major limitation to the early establishment of cover on these burned sites. This is supported by the fact that although all sites showed substantial increases in cover between the first and second sampling period (see below), precipitation was also below average during that period (see Study Sites Section). Even if we assume the poor establishment of seeded species was tied to below average rainfall, such years are hardly abnormal in southern California. Indeed, below average years are commonplace as the year to year variation in precipitation is extraordinarily large, with many months exhibiting a coefficient of variation in excess of 200% (Keeley and Keeley 1988).

Peak Vegetation Recovery on Seeded Sites and Unseeded Sites

Vegetative cover at the end of spring in late May to early June 1994, is presented for the 10 seeded sites in the Old Topanga burn (Fig. 2). The seeded species *Trifolium hirtum, Vulpia myuros* and *Bromus hordeaceous* were widespread, but on 7 of the 10 sites peak cover did not exceed 1% ground surface cover. Maximum cover by these species was 8% ground surface cover on the Puerco Canyon Site 2, however, natural regeneration was more than an order of magnitude greater (Fig. 2).

Comparing these seeded sites with the 12 unseeded sites in the Green Meadow burn (Fig. 3), shows little difference in pattern of postfire recovery. In both burns, peak cover ranged from about 25% to over 100% ground surface covered (>100% arises when plant canopies overlap). Using a 1-tailed t-test to test the hypothesis that seeded sites had greater vegetative cover showed no significant difference ($P > 0.05$) between seeded and non-seeded sites for the following vegetation parameters: (1) percentage ground surface covered, (2) annual cover, (3) herbaceous perennial cover, (4) shrub cover, and (5) suffrutescent cover.

There were, however, a few vegetation parameters that were significantly different between seeded sites in the Old Topanga burn and the non-seeded sites in the Green Meadow burn. The number of non-native exotic species was significantly greater on the Old Topanga burn sites (7.1/site vs 3.4/site for the Green Meadow burn sites, $P < 0.001$). Since two of the non-native seeded species, *Trifolium hirtum* and *Vulpia myuros,* were present on all of the Old Topanga sites and absent from the Green Meadow sites, the postfire management practice of aerial seeding likely accounts for differences in number of non-native species on these two burns.

Species richness was also significantly greater on the Green Meadow burn sites at the 100 m^2 scale (15.4/plot vs 11.6/plot for the Old Topanga burn sites, $P < 0.05$) and at the 1 m^2 scale (6.8/subplot vs 4.4/subplot for the Old Topanga burn sites, $P < 0.01$). In light of the rather poor establishment of seeded species on the Old Topanga burn sites, it seems unlikely that the presence of seeded species accounts for reduced species richness on the Old Topanga sites. Different histories of land use could play a role in these patterns. The greater population density in the eastern portion of the Santa Monica Mountains may play a role; e.g., leading to increased establishment of non-native species which could have contributed to loss of native biodiversity. Of course regional floristic differences can not be ruled out.

Patterns of Postfire Recovery on all Sites

Patterns of species richness vs scale were remarkably similar between all sites from both burns (Fig. 4). One noteworthy feature of these biodiversity patterns

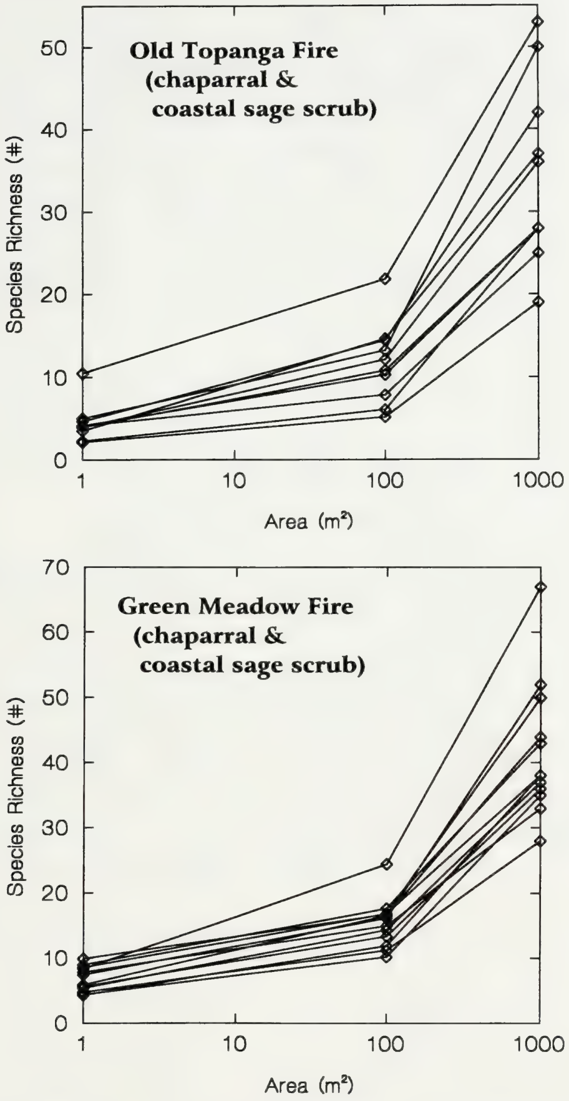

Fig. 4. Plant species richness at 1 m^2, 100 m^2, and 1000 m^2 for chaparral and coastal sage scrub sites in the Old Topanga burn and the Green Meadow burn.

is that they are unlike other Mediterranean climate ecosystems, which show a linear relationship on a semi-log scale (e.g., Bond 1983; Specht 1988). Relative to Australian heath and South African fynbos, these coastal sage scrub and chaparral sites have similar species richness at the scale of 1 m^2 and 1000 m^2 but are depauperate at 100 m^2.

Considering all sites collectively, species richness at each of the three scales was tested for their correlation with the site characteristics listed in Tables 2, 3, & 4. At all scales, the only site factor significantly correlated with species richness was total annual solar insolation (Fig. 5). Thus, richness is greatest on the cooler, moister, north-facing slopes than on the hotter south-facing slopes.

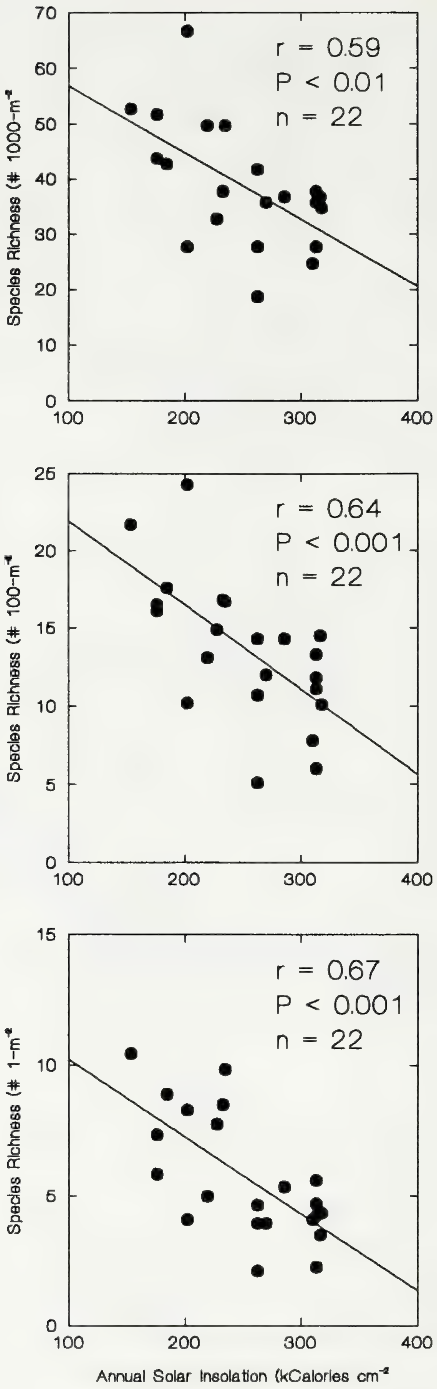

Fig. 5. Correlation between annual solar insolation (calculated from slope aspect, inclination and latitude) and species richness at 1 m^2, 100 m^2, and 1000 m^2 for all sites combined.

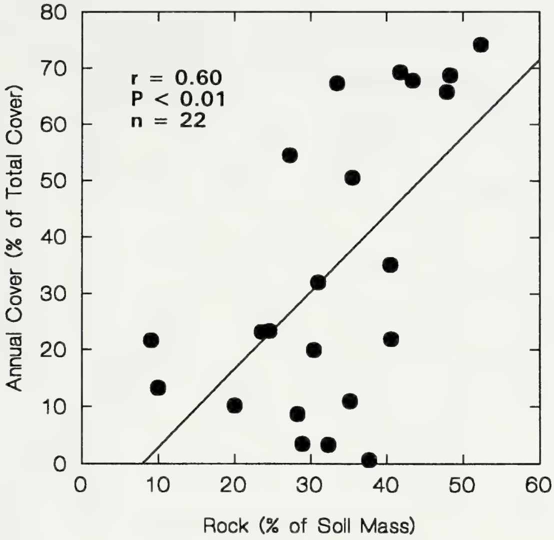

Fig. 6. Correlation between percentage (by weight) of rocks in soil and proportion of total cover by annual species, for all sites combined.

Several other vegetation characteristics were significantly correlated with site factors. The proportion of total cover derived from annuals was significantly correlated with the percentage, by mass, of rocks in the soil (Fig. 6). Thus, across all sites, annuals are more common on rocky sites. The proportion of herbaceous perennials comprising the postfire plant cover was negatively correlated with the fire severity index 1 (Fig. 7). Since uniformly, herbaceous perennials almost always are present on recent burns as resprouts from underground vegetative parts

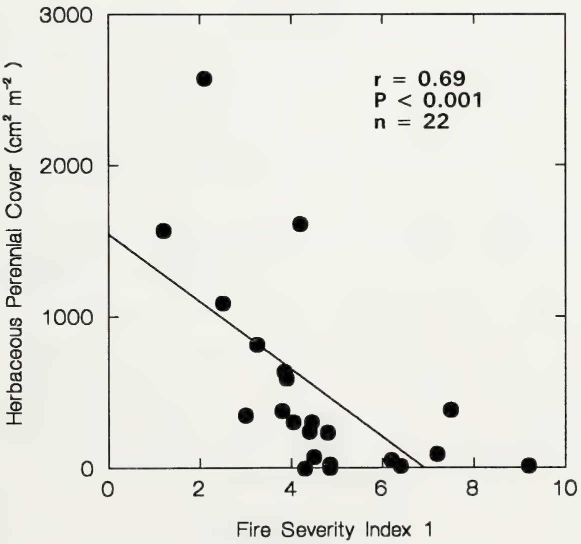

Fig. 7. Correlation between fire severity and proportion of total cover by herbaceous perennial species, for all sites combined.

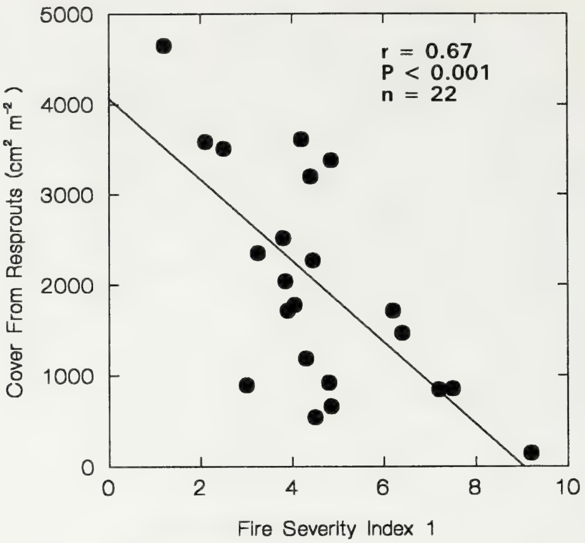

Fig. 8. Correlation between fire severity and cover from resprouts from herbaceous perennial and shrub species (annuals and suffrutescents regenerate entirely by seed after fire), for all sites combined.

(Keeley and Keeley 1984; Keeley, unpublished data from this study), it is not surprising that the cover from resprouts (both herbaceous and woody species) was also negatively correlated with this same index of fire severity (Fig. 8). It seems plausible that higher fire severity reflects higher fire intensity and destruction of underground vegetative organs. However, reduced herbaceous perennial cover was apparently compensated for by annuals and other growthforms, thus there was no significant correlation between total cover and fire severity.

Conclusions

This study compared postfire plant recovery on the Green Meadow burn, which was managed passively by relying solely on natural regeneration, with recovery on the Old Topanga burn, which was actively managed by aerial seeding of mostly non-native annual grasses and forbs. Establishment of the non-native seeded species was very poor and largely insignificant, relative to the natural regeneration. The single native species seeded on these sites comprised a minor portion of the seed mix and contributed little to the postfire cover. Comparing recovery on the Old Topanga burn and Green Meadow burn, there was no significant difference in plant cover on the two burns. Aerial seeding did contribute to a significantly greater number of non-native species on the Old Topanga burn, but it is unknown whether or not this will have any long term impact. The patterns observed in this study are consistent with those summarized in the recent synthesis of research on postfire seeding (Keeley and Scott 1995). Here, as in other regions, postfire seeding is not a reliable means of increasing plant cover, and thus is not a reliable means of reducing erosion and sedimentation after wildfires.

Acknowledgments

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A New Freshwater Clingfish (Pisces: Gobiesocidae) from Baja California Sur, México

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Abstract.—A new species of freshwater clingfish is described. The species differs from other known freshwater species of the genus *Gobiesox* by its morphometrics, morphology, tongue position, insertion and number of teeth and by the closer position of the anus to the anal fin. This is the seventh known freshwater species of clingfish of the genus in North America, the first in the Nearctic and the second endemic freshwater fish from the Peninsula of Baja California.

Resumen.—Se describe una nueva especie de pez "cucharita" de agua dulce. La especie se diferencia de otras especies dulceacuícolas del género *Gobiesox* por sus medidas morfométricas, morfología, posición de la lengua, la inserción y número de dientes y por la posición del ano más cercano a la aleta anal. Esta es la séptima especie conocida del género en aguas dulces en Norteamérica, la primera en la región neártica y la segunda especie endémica de la península de Baja California.

The family Gobiesocidae has a large geographic distribution and is composed of eight subfamilies (Briggs 1993). One subfamily, Gobiesocinae, includes nine genera and ca. 60 species distributed almost exclusively in tropical and subtropical waters of America (Briggs 1955). The most diverse genus in the subfamily is *Gobiesox* Lacepède, which contains a great proportion of species inhabiting rocky or coralline habitats in the neritic zone. There are some exclusively freshwater species that may be classified as the vicarious or complementary component of Myers (1963). These include the Western American species *G. potamius* Briggs, *G. juradoensis* Fowler, *G. fulvus* Meek, *G. mexicanus* Briggs and Miller, *G. fluviatilis* Briggs and Miller, the new species described here, and the Eastern North American *G. nudus* (Linnaeus).

In Mexican freshwater, two species, *G. fluviatilis* and *G. mexicanus,* have been reported (Briggs and Miller 1960; Burr and Buth 1977; Espinosa Pérez et al. 1988). Two other species, *G. strumosus* Cope and *G. adustus* Jordan and Gilbert, have been collected in brackish water in the estuaries of Río Tuxpan, Veracruz, and coastal lagoons and tidal flats of Sonora, Sinaloa, and Nayarit (Castro-Aguirre 1978).

The specimens that are the basis for the description of the new species were collected during a biological field trip near the southern portion of the Sierra de la Giganta, Baja California Sur, close to the town of Pocitas (approx. 100 km north of La Paz). This finding is biogeographically interesting, and provides evidence for potential speciation patterns in the genus. In particular, it offers some clues to the origin and adaptation of the freshwater fish fauna of Baja California Peninsula, which has a very low diversity (Follett 1961). *Fundulus lima* Vaillant and the new gobiesocid are the only reported endemic freshwater fishes to Baja California.

METHODS

Counts and measurements follow Briggs (1955) and Briggs and Miller (1960). Measurements were made using dial calipers and presented as thousandths of standard length (SL). IBUNAM-P is the abbreviation of the Instituto de Biologia, UNAM fish collection, formerly UNAM in Leviton et al. (1985).

RESULTS

Gobiesox juniperoserrai n. sp. (Fig. 1).

Holotype.—IBUNAM-P 7606, male 105.2 mm SL, Las Pocitas (Poza del Vado), Baja California Sur, México, collected by Paulino Pérez and party, 12 May 1986.

Paratypes.—IBUNAM-P 7607 (2) collected with the holotype, which are cleared and stained (67.4–98.2 mm SL).

Diagnosis.—A *Gobiesox* with poor development of head papillae and smooth margin of upper lip. Lower jaw without accessory incisor-like teeth and two rows of flat incisor-like teeth. Tongue completely adhered to mouth floor. Origin of dorsal fin closer to base of caudal fin than to upper part of base of pectoral fin. Anus much closer to base of anal fin than to pelvic disc margin. The three specimens have head contained 2.2–2.7 times in SL, and 27 vertebrae. Each part of region C of the disc has 5–6 longitudinal rows of papillae and 7–8 rows cross with region A of the disc. Dorsal fin rays 13 (13–14), anal fin rays 7 (7–8), pectorals fin rays 22 (22–24), and caudal fin rays 13 (13–14).

Description.—Depressed body, depth 5.3–5.6 in standard length; short caudal peduncle, least depth 0.6–0.7 in its length. Head very broad, width 2.2–2.7 and length 2.3–2.6 in SL. Eye 2.5–3.2 in bony interorbital space, and 6.7–7.7 in head length. Short and rounded snout, 2.9–3.2 in head length. Posterior nostril tubular, located at anterior edge of eye; anterior nostril tubular, provided with bilobed dermal flap. Upper jaw anteriorly with 5–6 pairs of incisor-like teeth with rounded edges; posteriorly on each side, there are canine-like teeth with flat or slightly rounded edges; inner row with irregularly small conical teeth of variable size. Lower jaw with two rows of teeth, anterior row with 5–6 pairs of compressed, flat incisor-like teeth followed by a single series of 8 conical canine like-teeth without accessory incisor-like teeth. The second row is a patch of very small conical teeth behind the two frontal pair of incisors (Fig. 2a–b). The tongue is completely adhered to the floor of the mouth. Five shallow and small rakers on the posteriormost gill arch. Upper attachment of gill membrane opposed to the 4th pectoral fin ray. Subopercular spine weak and small, almost inperceptible. Postdorsal-caudal distance 1.8 in dorsal length. Length of disc is 2.9 in standard length. Anus is much closer to anal fin origin, and the urogenital papilla is formed as a single structure (fig. 2c).

Coloration.—In alcohol, the dorsal and lateral sides are evenly medium brown, with small black spots scattered on the body. The dorsal, anal and caudal fins are

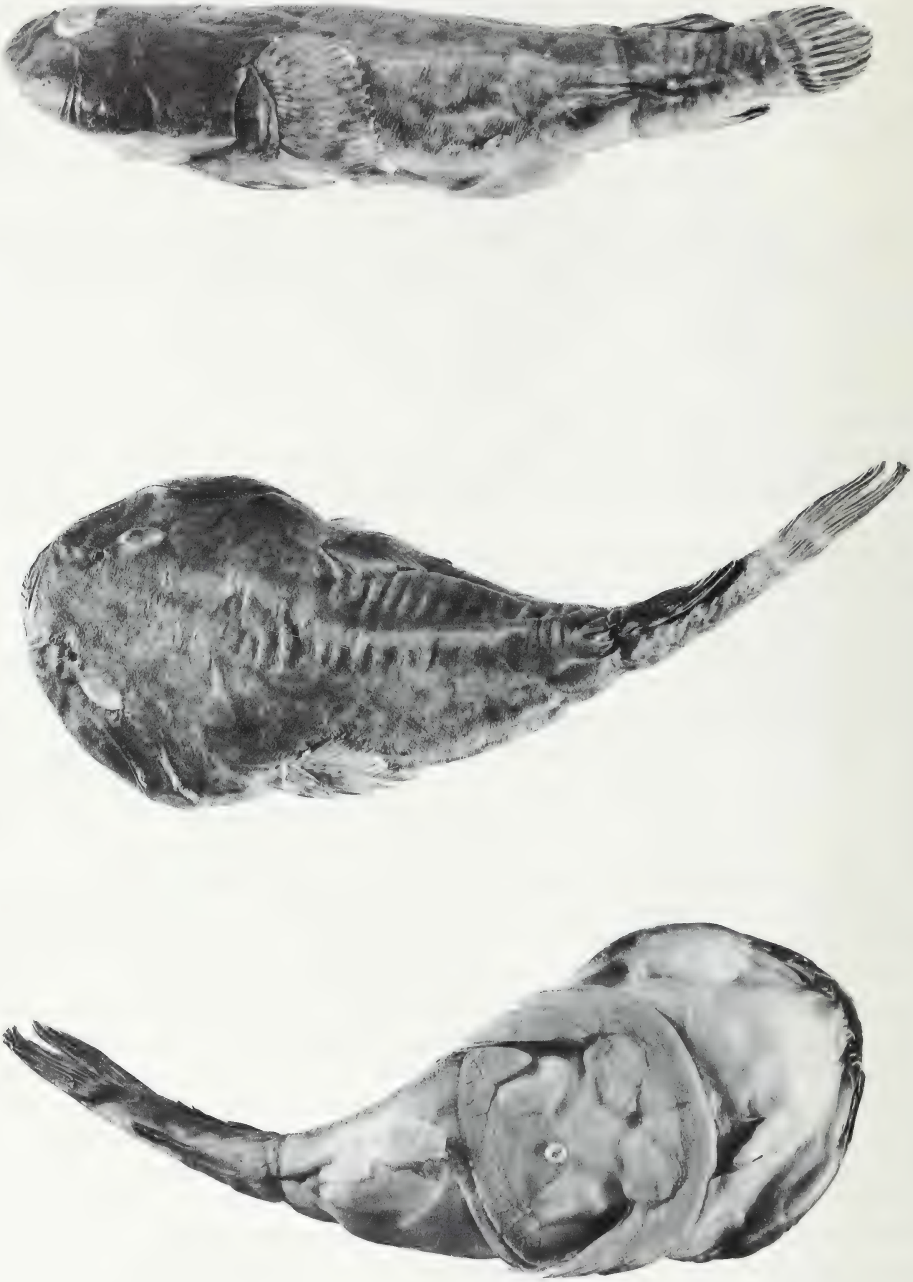

Fig. 1. Holotype of *Gobiesox juniperoserra* lateral, dorsal and ventral view.

brown except in their bases and two caudal pale bars. Ventral surface of body is translucent; the area near the vent is almost colorless.

Habitat.—The types were collected in a small semipermanent creek called Pozas del Vado. It is located at the lower end (SW) of Sierra La Giganta, B.C.S.

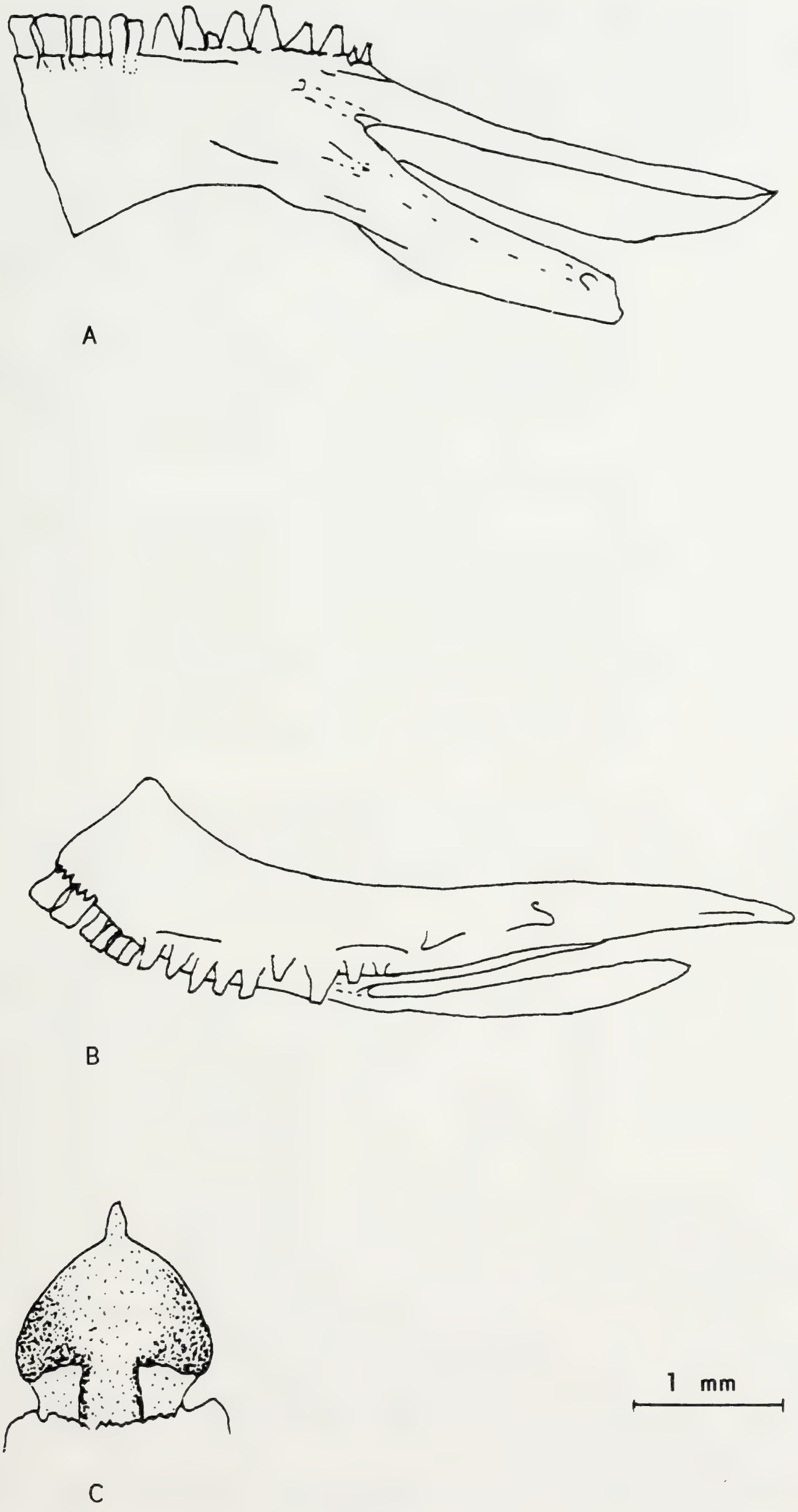

Fig. 2. Left dentary a) lateral and b) dorsal view. c) Urogenital papillae.

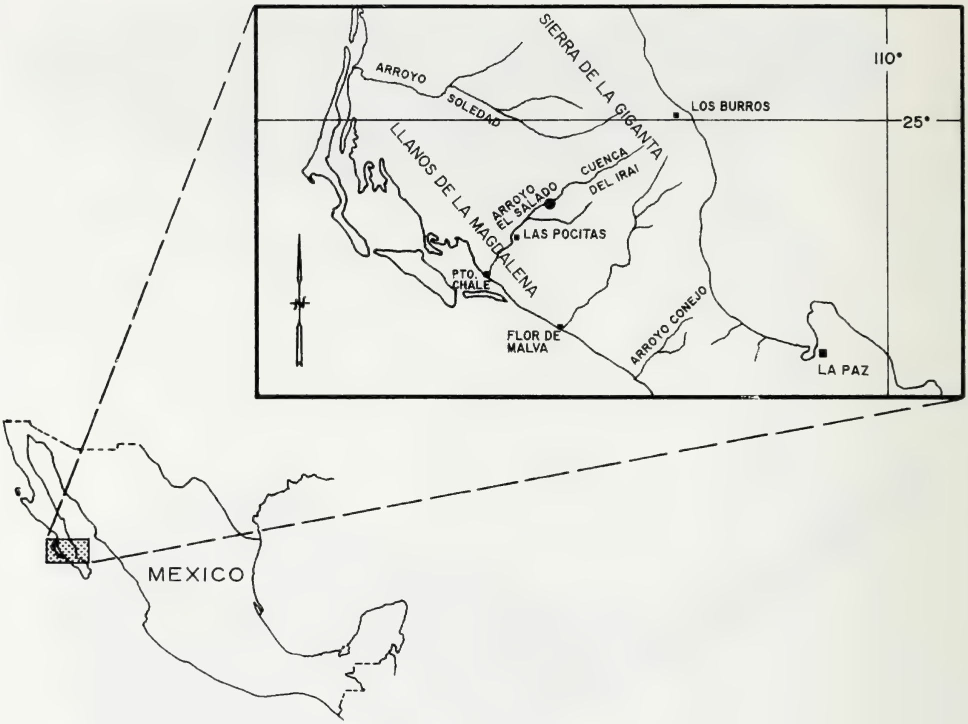

Fig. 3. Type locality of *Gobiesox juniperoserra.*

(Fig. 3). The average height above sea level varies from 30 to 60 m. This area is located between 24°28′ and 24°52′N and 110°49′ and 111°49′W. Climate is extreme, being the most arid of the semidry climates of the Peninsula, with a mean annual temperature ranging from 20 to 22°C, and rainy seasons, in summer and winter.

The hydrologic basin of the area is reduced to a few small natural pools (=pozas, origin of the generic name of the region). The creeks are located along two canyons that merge. Those located in the southern region merge directly or indirectly with a small river that goes to the Flor de Malva estuary, opening to the Pacific. Rivers to the north and west of the Mesa de Irai plain are joined with other small channels that occasionally reach the Punta Chale estuary opening into Bahía Almejas, at the lagoon system of Bahía Magdalena, Baja California Sur.

The Pozas del Vado are a series of ponds watered by small springs. Their diameters range from two to six meters, with a depth from 20 to 50 cm. They remain isolated during the dry season, but become interconnected at the onset of the rains and give rise to the two rivers mentioned above. This ecological setting can be compared to some biotopes located in mainland México, particularly in the states of Jalisco, Michoacán, Guerrero, and Oaxaca.

The floor of these water bodies is composed of sand, gravel, and rocks. Toward the edges of the ponds, due to accumulation and decomposition of organic matter small muddy beaches are formed. Large rounded rocks of rhyolithic material located in the rivers are common.

The aquatic vegetation collected in this locality is represented by the algae

Chara sp., and the monocotyledon *Potamogeton* sp. The fresh water fauna is not diverse. To date, larvae of insects like odonates and corixids, and some amphibians, probably *Bufo marinus,* have been identified. Other organisms include freshwater shrimps (*Macrobrachium americanus, Palaemon* sp.) and fishes (*Agonostomus monticola, Gobiomorus maculatus, Awaous trasandeanus, Eleotris picta,* and the exotic *Poecilia reticulata*).

Etymology: The name *juniperoserrai* is for Fray Junípero Serra, Jesuit missionary, evangelizer, and explorer of the Alta and Baja California region during the Colonial epoch.

Key to the Mexican freshwater species of *Gobiesox*

1. Anus closer to anal fin origin than to rear margin of disc; 13 (13–14) rays in dorsal fin; lower jaw with two rows of incisor like teeth and with out accessories incisor-like teeth; tongue adhered to the floor of the mouth . . . . *G. juniperoserrai*

– Anus midway or closer to rear margin of disc than to anal fin origin; tongue not adhered to the floor of the mouth 2

2. Anus midway between rear margin of disc and anal fin origin; lower jaw with a single row of incisor-like teeth; 10 (9–10) rays in dorsal fin and 8 (7–9) rays in anal fin . . . . *G. fluviatilis*

– Anus closer to rear margin of disc than to anal fin; lower jaw with several rows of incisor-like teeth and accessories incisor-like teeth in front row; 12 (11–12) rays in dorsal fin and 7 (6–8) rays in anal fin . . . . . *G. mexicanus*

Discussion

The discovery of *Gobiesox juniperoserrai* in fresh waters of the southern part of Baja California Peninsula is important from a biogeographic point of view. The closest relative of *G. juniperoserrai* based on morphological and morphometric characteristics seems to be *G. mexicanus,* distributed from Río Cuitzmala, Jalisco, south to the Tehuantepec Isthmus, Oaxaca. This distributional pattern supports the hypothesis of Castro-Aguirre and Torres-Orozco (1993), who suggested that the fish fauna of the southern part of the Sierra de la Giganta has a great affinity with the fresh water fish fauna of the southern part of Jalisco and Michoacan. Hausback (1984) has argued that this geographic area of continental Mexico corresponds geologically with the southern part of the Baja California Peninsula.

The origin of *Gobiesox juniperoserrai* could therefore be hypothesized as the result of allopatric processes began with the drifting of the Peninsula toward the northwest, perhaps during Miocene or Pliocene time. The geographic isolation of the populations, and the time elapsed may be the main factors giving rise to the new species from a relative close to *G. mexicanus.*

Besides the morphological differences between *G. fluviatilis, G. mexicanus,* and *G. juniperoserrai,* there are important distinctions in their habitat preferences. *Gobiesox fluviatilis* is an important component of the mountain rivers, especially those located between 750 and 1000 meters above sea level (Briggs and Miller 1960; Burr and Buth 1977).

Although the three species belong to the complementary fish component of

Myers (1951, 1963), it is evident that *G. mexicanus* may be included in the Neotropical fish fauna, whereas *G. fluviatilis* could be cataloged as a nearctic element. *Gobiesox juniperoserrai* represents, therefore, a northern species with Neotropical ancestry.

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Redescription and Taxonomic Comparison of Three Eastern Pacific Species of *Muricea* (Cnidaria: Anthozoa)

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Abstract.—Colony morphology, sclerite analysis, color pattern and habitat can be used to differentiate between two common species of gorgonians, *Muricea fruticosa* and *M. californica,* in southern California. Examination of type material indicates that *M. appressa* (Verrill) is not a synonym of *M. californica,* but considerable taxonomic confusion still exists regarding the nomenclature of eastern Pacific species of *Muricea.*

Species of *Muricea,* commonly called rusty sea fans or spiny sea fans, are conspicuous colonial cnidarians of subtidal rocky areas of southern California. On shale reefs, these large colonies can compete with giant kelp for space for settlement (Honma and Patton 1994). Members of the genus are characterized by having a heavily branched colony described as fan- or tree-shaped. The calyx (the "cup" covering the retracted polyp) is formed by sclerites, and projects away from the coenenchyme, forming a distinct lower "lip." The polyps are scattered around the branches instead of occurring in rows.

The nomenclature of species of *Muricea* in southern California has been confused. Two or three species have been reported, depending on the author. Most eastern Pacific species of this genus were described by A. E. Verrill (1869). Although Verrill provided detailed descriptions of the sclerites, he often failed to state from which part of the coenenchyme the sclerite came. Many of his specimens were dredged and lacked detailed notes on habitat or depth. Kükenthal (1924) reviewed many eastern Pacific species and provided more details on the sclerites, but failed to provide illustrations for comparison. Aurivillius (1931, p. 104) described additional species, but commented that the new species "correspond in several characteristics with species already known" and "have by me nevertheless been provisionally determined as new ones by reason of my not having had at hand any material of the species previously established, and since I do not find myself able to identify them only from existing descriptions." Grigg (1972) noted that branch diameter in species of *Muricea* could vary according to exposure to current flow. Other species of gorgonians are known to vary in color and colony shape within a species.

No new species of *Muricea* have been described from the eastern Pacific since 1931, nor has anyone published further descriptive details on the species from California or attempted to compare series of specimens to determine which occur strictly in warmer seas, which are widespread, and which (if any) are endemic to cooler waters of California and Baja California. Grigg (1972, 1977) studied ecology of species of *Muricea,* but did not continue taxonomic work on the species. Aurivillius (1931), Grigg (1977) and Haderlie et al. (1980) mentioned that *M.*

californica might be a synonym of *M. appressa,* yet gave no detailed evidence to support this.

There seems to be a consensus among biologists in southern California that *M. californica* is the common species found in the area, although written and detailed evidence for this identification is lacking. Ricketts et al. (1985) refers to this species; the guidebooks by North (1976) and Gotshall (1994) also use this name. However, Haderlie et al. (1980) called the common species *M. appressa. Muricea californica* has been distinguished in the field from *M. fruticosa* by polyp color—the former having yellow polyps and the latter having white ones (North 1976; Gotshall 1994), but Brusca (1980) reported that *M. californica* could have white or yellow-orange polyps.

During recent diving trips to southern California, we obtained fresh specimens and color underwater photographs of species of *Muricea.* We noticed consistent differences in colony morphology and color between certain specimens collected in caves or overhangs and those growing in the open on rocks. We also photographed a colony having white polyps on one set of side branches and yellow polyps on the other branches. These observations led us to compare type material and other preserved specimens of *Muricea* species with our specimens, and to prepare detailed descriptions of two common species.

Methods

We obtained fresh specimens of *Muricea* species by collecting by hand while diving on the lee side of Santa Catalina Island near the Isthmus. Specimens were preserved in 10% formalin. We also collected specimens cast ashore after winter storms near Point Fermin, Los Angeles County. We examined preserved material previously collected by one of us (MKW) off Santa Catalina Island and along the Los Angeles Harbor Breakwater. These specimens have been retained in the invertebrate zoology teaching collection at Texas A&M University pending further study. We borrowed type material of *M. appressa* and specimens identified (possibly by E. Deichmann) as *M. californica* (but not types) from the Museum of Comparative Zoology, Harvard University, and types of *M. fruticosa* from the Peabody Museum of Natural History. The types and most of the other material was dried. We were unable to locate the type material of *M. californica,* which may still exist in a European museum.

Species of *Muricea* were photographed alive underwater during this study. These photographs were compared with others taken during previous diving trips and with those in published works (North 1976; Gotshall 1994; Haderlie et al. 1980; Ricketts et al. 1985). In addition, Jack Engle of the Channel Islands Research Program, University of California at Santa Barbara, donated a photograph of *Muricea* from Santa Catalina Island.

Pieces of dried specimens were soaked in 10% formalin overnight before sclerite analysis. Sclerites were removed carefully from the pieces and examined at 10×, then were sketched at 40×, 100× and 400×. Sclerites were measured to the nearest 0.1 mm. Sclerites from the axes of the branches and calyces were differentiated. Colony shape, branch shape, color patterns and sclerite types were compared with type materials.

Results

Our specimens from southern California match the type material of *M. fruticosa* Verrill and material previously identified as *M. californica* Aurivillius. All of these specimens are distinct from the type material of *M. appressa* Verrill. Table 1 provides a summary of important differences between these species. We provide new descriptions of these species herein.

Muricea fruticosa Verrill
Figs. 1–4, 8A, 8B, 8C

Muricea fruticosa Verrill 1868: 428, pl. 8.

Material examined.—Fragments of type specimens, Peabody Museum of Natural History, Yale University catalog numbers 1574b, 1574d, collected by pearl divers, Pearl Islands, Panama, 11–14 m, 1866. CALIFORNIA, U.S.A.: One colony, Isthmus Reef, Santa Catalina Island, 11 m, 26 May 1972, M. K. Wicksten; 30 mm wide, 70 mm high. One colony, Ship Rock, Santa Catalina Island, 20 m, 17 Dec. 1994, M. K. Wicksten, 30 mm wide, 50 mm high.

Description.—Colony densely branched, bush-shaped. Color mostly deep reddish-orange, characteristically fading from reddish-orange of tips and branches to light yellow color in main trunks and base. Polyps pure white. Axis clear yellow at tips, dark brown at base. Branching irregularly dichotomous, distinctly curving, especially in smaller branches near ends. Terminal branches not tapering, either end evenly or are clavate. Calyx projecting out 45 degrees from branch when closed, nearly 90 degrees with polyp extended. Lower lip of calyx sharp and long with very large, distinct sclerites which lie parallel to each other and project past upper margin of lower lip, giving colony a prickly feel when touched. Upper lip small or barely noticeable. Calyces close together but not overlapping, allowing outer coenenchyme to be seen easily between calyces. Calyx size and spacing varying with position on colony, larger and closer towards tips, more flat and spread apart near base. Outer coenenchyme characterized by extremely large sclerites, visible to naked eye, lying between calyces and curving around them (Fig. 1B); these sclerites may be missing near base of colony or in poorly preserved specimens. Outer coenenchyme sclerites reddish-orange, measuring up to 3 mm long, of several shapes: stout, blunt and truncate, having almost rectangular shape and evenly covered by small tubercles; irregularly fusiform and covered with tubercles; hook-shaped on one end, both ends curving inward, or one end forked and the other tapering to a point, these latter often covered on ends with small, sparse occasionally spiny tubercles, becoming more densely covered with tubercles toward the center (Fig. 2). Hook-shaped sclerites usually found around base of calyces. Inner coenenchyme sclerites distinctly smaller, color ranging from yellow to white, fusiform, often tapering to sharp point and covered with distinctly raised tubercles (Fig. 3). Calyx sclerites long, up to 1.6 mm, very irregular and oddly shaped, mostly fusiform, one end often forking slightly or very distinctly, evenly covered with distinct tubercles, with some unilaterally spinose spindles. Smaller calyx spindles thin, fusiform, with ends either rounded or tapering to point (Fig. 1).

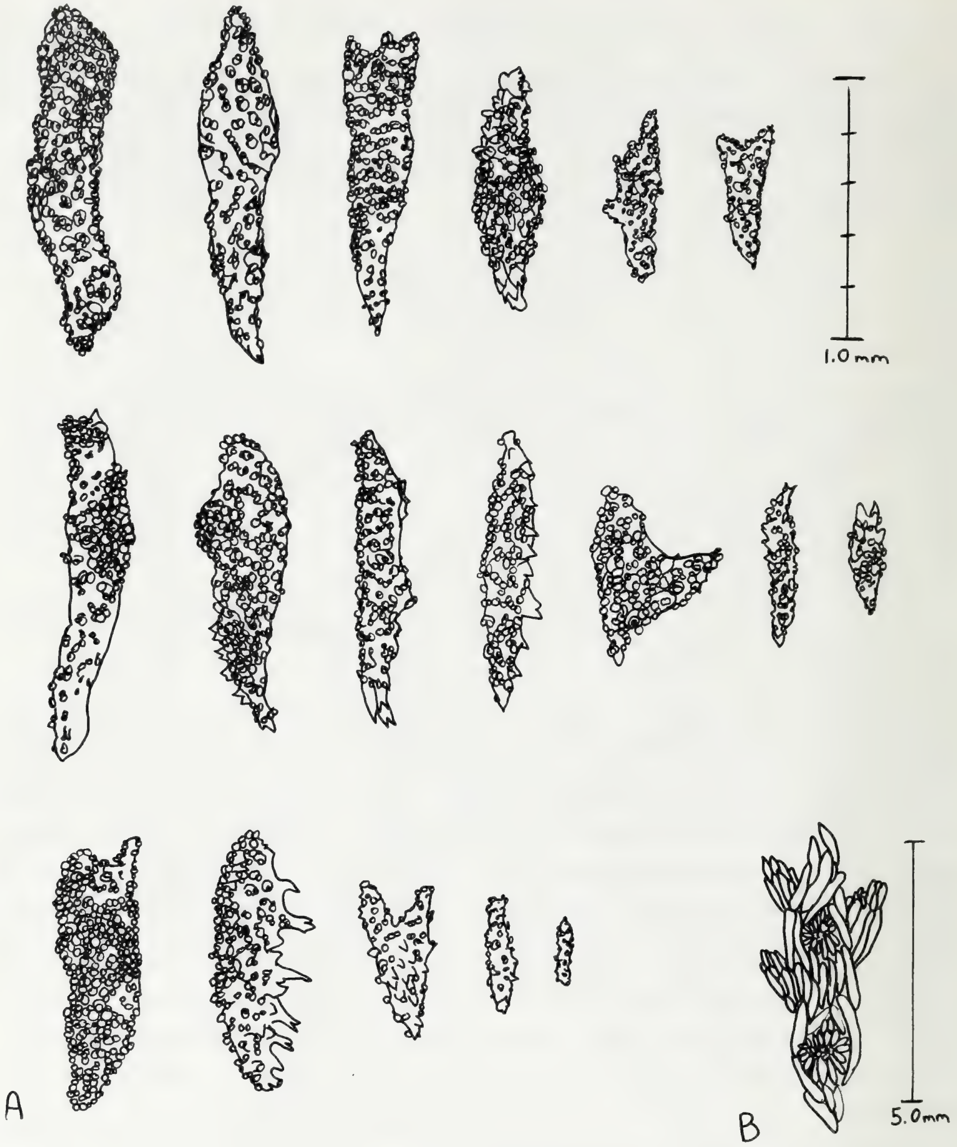

Fig. 1. *Muricea fruticosa* Verrill, 1869. Type, YPM 1574b. Pearl Islands, Panama. A, calyx sclerites; B, representation of sclerite arrangement on a branch.

Muricea californica Aurivillius
Figs. 5, 8D, 8E

Muricea californica Aurivillius 1931: 111, fig. p. 113.

Material examined.—Museum of Comparative Zoology, Harvard University, 1 colony with fragments, off Corona del Mar, California, 18 m, G. E. MacGinitie, collector, 25 July 1935. Maximum colony dimensions: 100 mm wide, 250 mm high, average branch width 5 mm. CALIFORNIA, U.S.A.: 10 colonies cast ashore, 1 preserved in formalin, others dried, near Point Fermin, Los Angeles

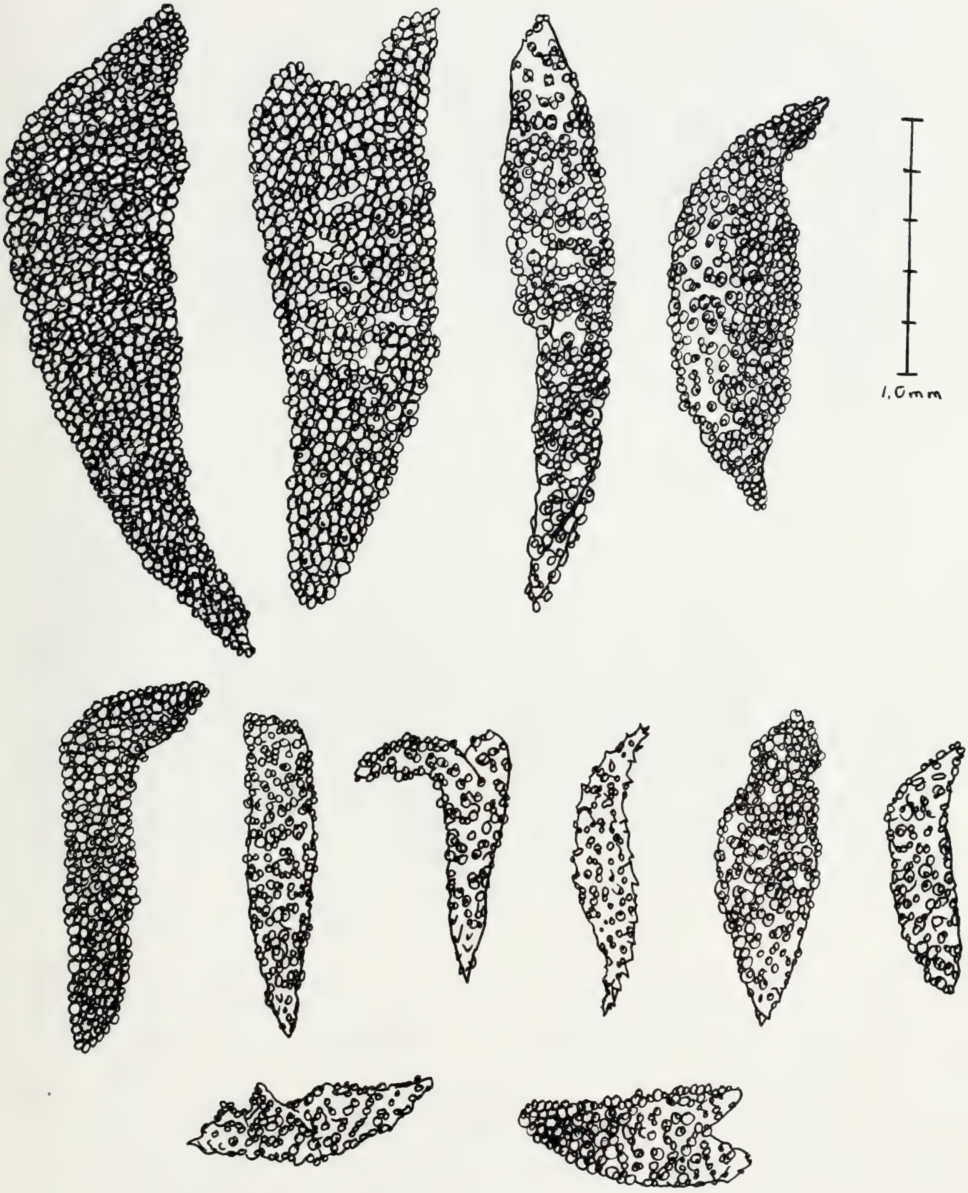

Fig. 2. *Muricea fruticosa.* Type. Outer coenenchyme sclerites.

County, California, 18 Dec. 1994, M. K. Wicksten. Type locality Santa Catalina Island, California.

Description.—Colony dark reddish-orange. Branches primarily in 1 plane, some primary and secondary branches extending out of plane; branches curving to lie parallel to main branch. Branching lateral, terminals of even thickness or tapering slightly. Axis reddish-brown at base, becoming light yellow-brown at tips. Polyps golden orange, bright yellow, pale yellow or white; all polyps of 1 branch of same color; rarely, more than 1 color of polyp per colony. Calyx pro-

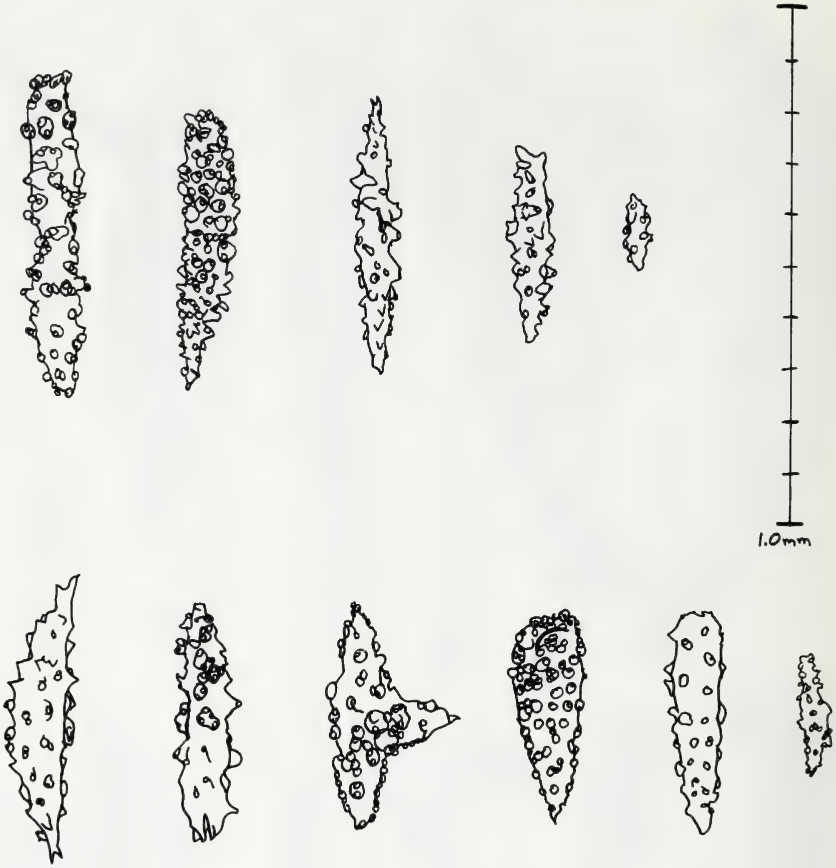

Fig. 3. *Muricea fruticosa.* Type. Inner coenenchynme sclerites.

truding from 45 to nearly 90 degrees away from branch when polyp extended; very elongated and conical in shape. When polyp not extended, calyx lying close to and curving into stem. Calyces set close together but not overlapping. Upper lip varying from without sclerites to having definite lip. Calyx sclerites small, up to 1.0 mm in length, closely set together, not projecting distally but smoothly placed on calyx. Sclerites club-shaped with large rounded spines or pointed tubercles projecting from clavate end, other end tapering and covered with tubercles (Fig. 5A). Outer coenenchyme mostly occluded by calyces; consisting of small sclerites, to 0.5 mm long, torch-like, with processes often continuing down one side, the other end tapering and covered with tubercles (Fig. 5B). Some spindles fusiform, bent slightly in middle, or having large processes in middle projecting outward. Inner coenenchyme spindles small, fusiform, set with distinct tubercles.

Muricea appressa Verrill
Figs. 6–7, 8F

Muricea appressa Verrill 1864: 444, pl. 8, fig. 13.

Material examined.—Museum of Comparative Zoology, Harvard University MCZ No. 380, dried; MCZ No. 383, 3 specimens in ethanol, "Panama, shallow

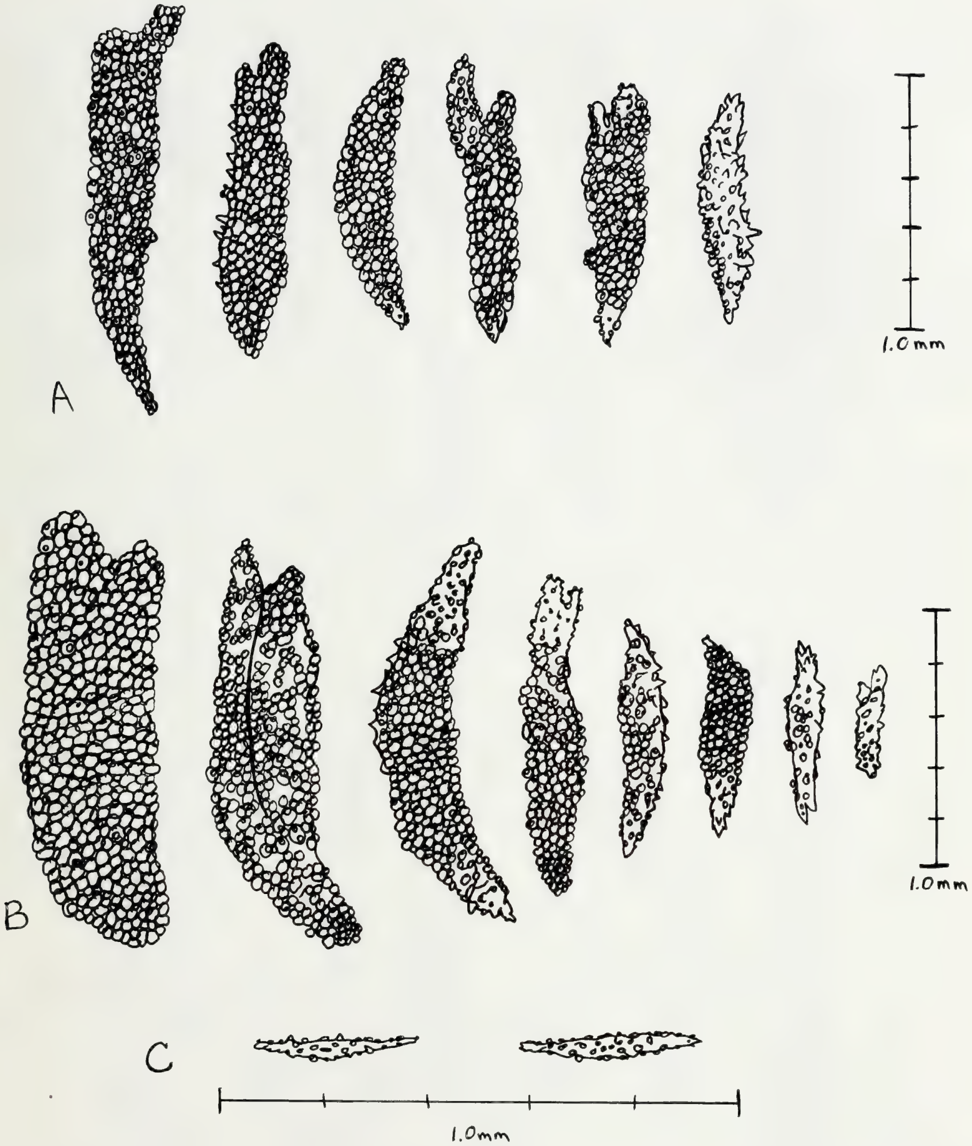

Fig. 4. *Muricea fruticosa.* Type. A, calyx sclerites; B, smaller yellow calyx sclerites; C, coenenchyme sclerites and sclerites surrounding calyx base.

water," P. H. Sternberg, July 1863. Maximum colony dimensions 9.2 cm high, 9.4 cm wide, terminal stem width 2.5 mm. Type locality Pearl Islands, Panama, also taken at Zorritos, Peru; Corinto, Nicaragua, La Paz, Baja California Sur, Mexico (Verrill 1864).

Description.—Colony light brick red. Growth strictly in 1 plane, distinctly fan-shaped, branching mostly dichotomous with terminals often clavate and curved inward. Some terminal branches of even thickness throughout. Several main trunks branching from base, branches growing outward and eventually curving to lie parallel to the branch of origin. Polyp color in life not recorded. Calyces small,

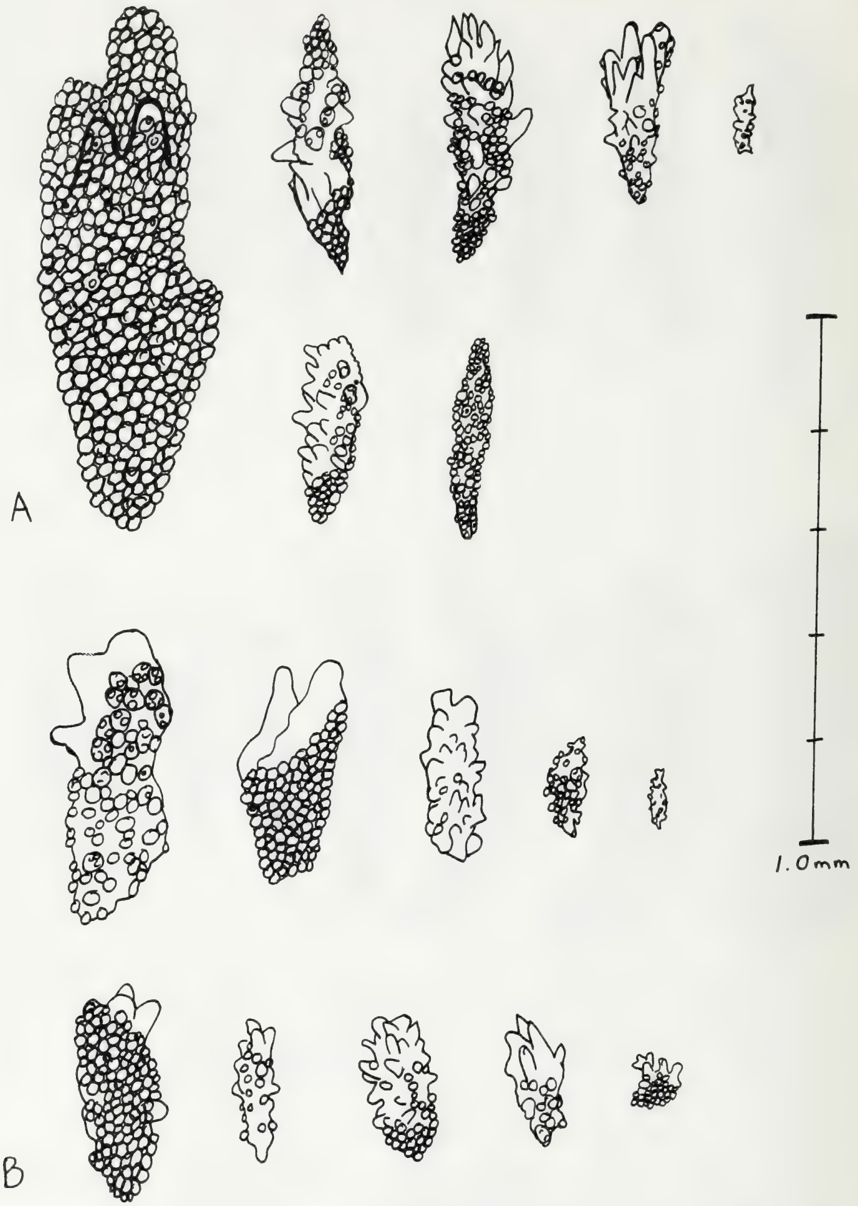

Fig. 5. *Muricea californica* Aurivillius, 1931. MCZ specimen, off Corona del Mar, California. A, calyx sclerites; B, coenenchyme sclerites.

crowded and overlapping, with very little outer coenenchyme visible behind them. Calyx tip curved back into stem, surface covered with rough sclerites which do not project outward. Calyx sclerites small, up to 0.6 mm, larger ones reddish-orange and smaller more yellow, orderly arranged on calyx, becoming distinctly smaller near summit of calyx. Larger sclerites club-shaped, swollen end having projecting large sharp or blunt spinules, other end acute and covered with tubercles. Smaller calyx sclerites club-shaped with enlarged spinules, curved and uni-

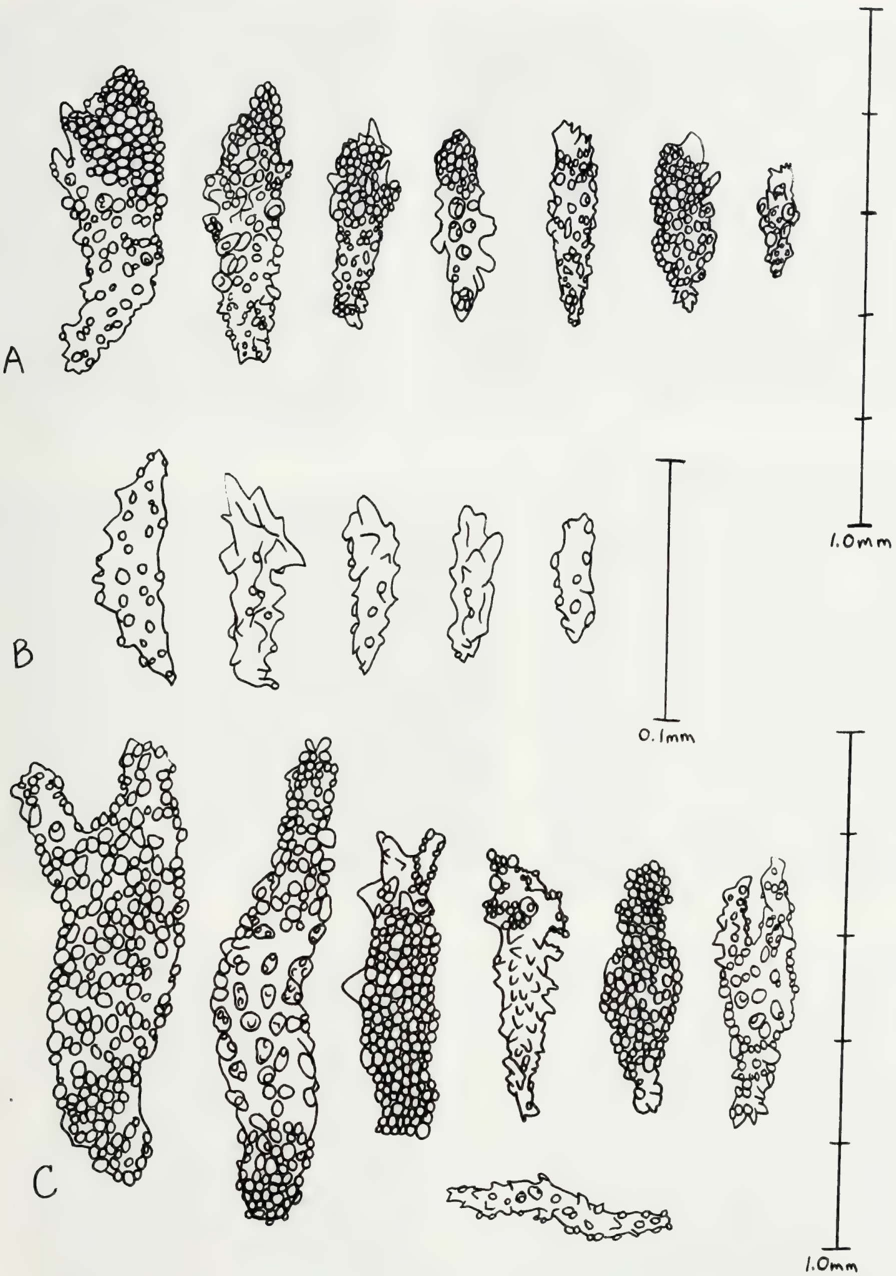

Fig. 6. *Muricea appressa* Verrill, 1864. Type, MCZ 380. Panama. A, larger calyx sclerites; B, small sclerites at calyx summit; C, coenenchyme sclerites.

laterally spinose spindles, or irregular with many spiny projections (Fig. 6B). Outer coenenchyme with small sclerites, largest one 1.0 mm, irregular, curved, occasionally bluntly forked, or fusiform with small distinct tubercles crowding ends and larger, more diffuse tubercles toward middle (Figs. 6C, 7B).

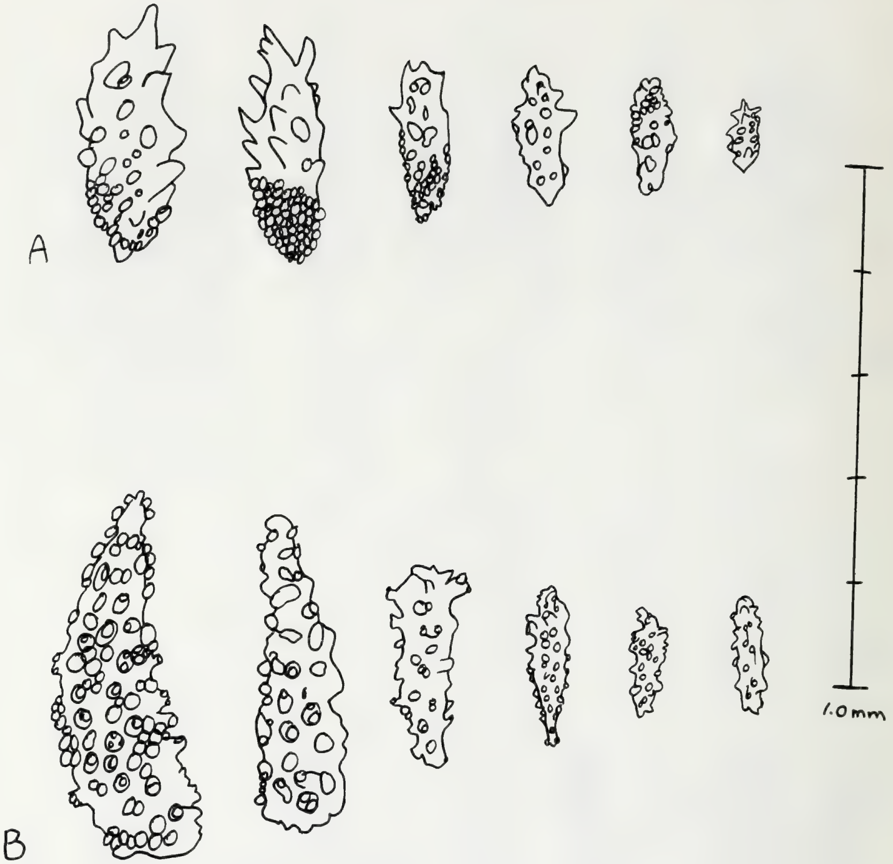

Fig. 7. *Muricea appressa.* Type, MCZ 383. A, calyx sclerites; B, coenenchyme sclerites.

Discussion

At present, 24 species of *Muricea* have been described from the eastern Pacific (Verrill 1869; Kükenthal 1924; Aurivillius 1931; Deichmann 1936; Stasny 1943). Some of these species have been described from only a few specimens, or even pieces of specimens. Verrill (1864) did not give adequate information on the locations of the sclerites within the colony, and used subjective characters such as whether a sclerite was "long" or "short." Kükenthal provided no illustrations and gave no basis for comparing calyx size. None of the existing descriptions provides much information on variation in color, growth form or size within a species, yet gorgonians are known to vary greatly according to all of these features. Because gorgonians generally live on subtidal rocky substrates, they were difficult to collect prior to the invention of SCUBA gear.

Of the three species discussed in this paper, *M. fruticosa* is the most distinct. The color pattern is characteristic: the colony seems to fade from reddish-orange in the distal branches and terminals to the light yellow or even almost white color on the proximal main branches and trunk. The arrangement of the outer coenenchyme sclerites also is characteristic. Extremely long sclerites, visible to the naked eye, lie prominently on the coenenchyme, often curving around the calyces. The

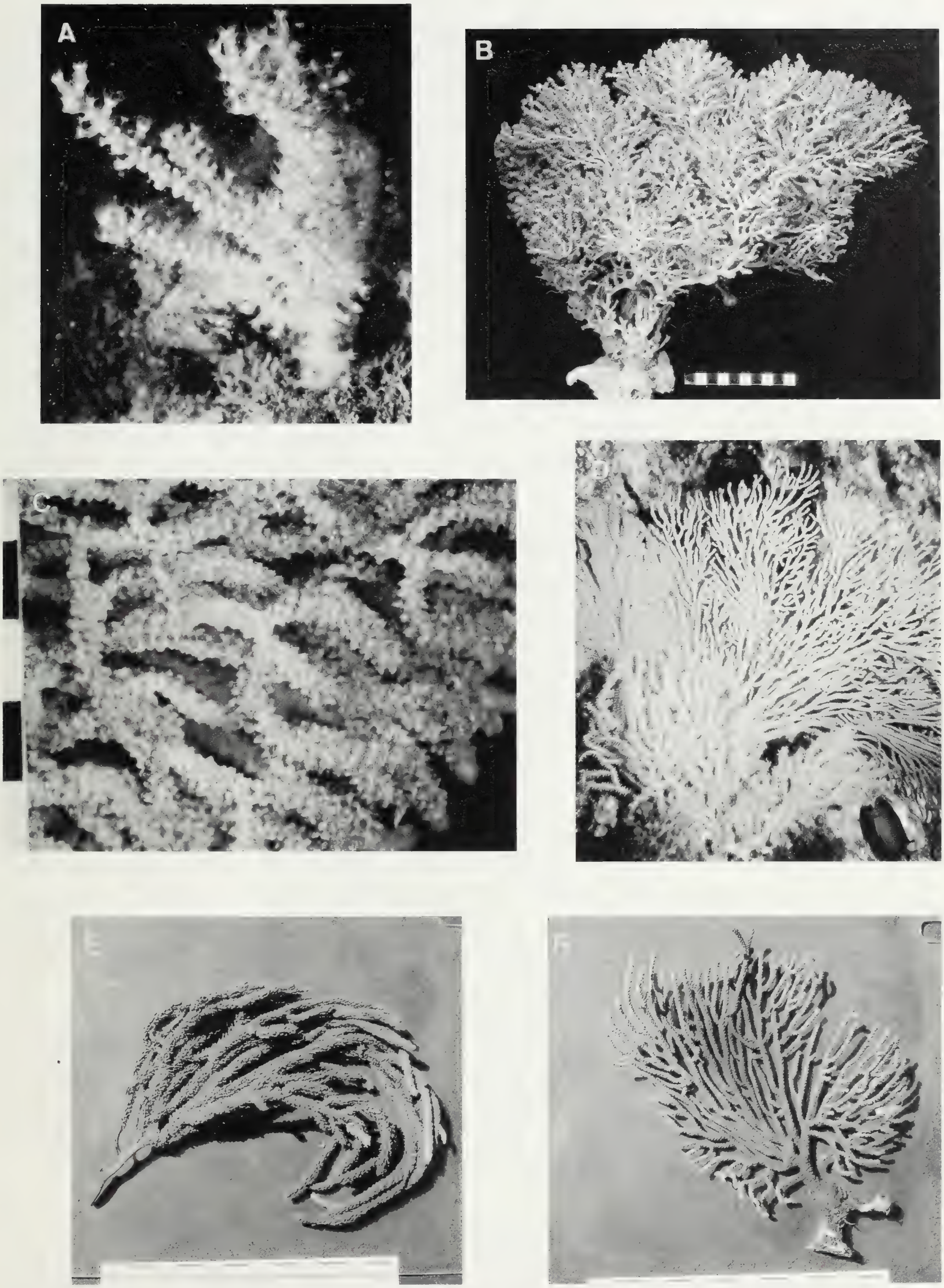

Fig. 8. A, *Muricea fruticosa* in life, San Pedro Breakwater, California; B, type specimen, C, detail of branches. D, *Muricea californica* in life, Santa Catalina Island, California; E, MCZ specimen. F, *Muricea appressa* syntype. Scale in cm. Figures B and C courtesy of Eric Lazo-Wasem, Peabody Museum of Natural History.

calyx sclerites, arranged side-by-side, project up away from the margin of the lower lip and give the calyx a ribbed appearance (Fig. 1B). The specimens that we have collected and photographed all lived inside caves, holes or cracks.

Based on comparison of the type material and the specimen from Corona del Mar, *M. appressa* is distinct from *M. californica. Muricea appressa* branches strictly in one plane and forms a fan-shaped colony, with terminal branches often clavate and curved inward. *Muricea californica* is not strictly planar and has terminal branches that are of even thickness or taper slightly. Its branches curve away from and eventually turn to run parallel to their branch of origin. In the former, the calyces are small, crowded, and distinctly overlapping; in the latter, the calyces do not overlap. In *M. appressa,* the sclerites of the calyx grow distinctly smaller near the distal edge of the lower lip. The outer coenenchyme sclerites of *M. appressa* are large and irregular, bent or occasionally bluntly forked or fusiform with small tubercles on the ends blending to larger tubercles in the middle. (See Table 1 for a concise comparison of the species). As of this writing, *M. appressa* has not been reliably reported from southern California. Verrill (1869) reported it to range from Baja California to Peru; de Ridder (1980) reported it from the Galapagos Islands. We have examined only preserved material of *M. appressa,* and therefore do not know its habitat or living color of the polyps.

Our specimens and observations suggest that *M. californica* displays a variety of colony forms and lives in diverse habitats. We have observed young colonies consisting of a single branch of less than 10 mm to very large ones estimated to be over 1 m in maximum dimension. The colonies usually were fan-shaped, but we also collected shrubby ones. We photographed a specimen at the San Pedro Breakwater having both white and yellow polyps on the same colony; J. Engle provided us with a photo from Santa Catalina Island showing another bicolor colony. We have seen more colonies with yellow to orange polyps than white ones, but have no information on whether the color of the polyps is related to depth, habitat or geographic location. Colonies were found living at the lowest intertidal level on the Los Angeles Harbor Breakwater at San Pedro to depths of over 30 m along Santa Catalina Island. The colonies were found on granite and other hard rocks, shale reefs, pilings or rarely attached to shells.

Grigg (1972, 1977) reported that there was no significant direct competition between *M. californica* and *M. fruticosa* off La Jolla, California. Both species usually grew at right angles to the dominant current flow. At the Los Angeles Harbor Breakwater, where *M. californica* and *M. fruticosa* co-occurred, the former generally grew exposed on outer surfaces of rocks and entrances to holes, while the latter was in the interior of holes or growing on the lower surface of overhangs.

We have observed species of *Muricea* growing on rocks under kelp beds at Anacapa Island and near La Jolla, California, but have not examined specimens from either location. We suspect on the basis of habitat, size and color that these were *M. californica.* Grigg (1977) reported this species to range from south of Point Conception, California to Santa Maria, Baja California, Mexico; Brusca (1980, p. 65) said that it ranged from Anacapa Island, California "south as far as Panama."

At present, it is not possible to provide a synonymy of the local species of *Muricea,* because we have not had the opportunity to examine the specimens on

Table 1. Comparison of *M. appressa, M. californica,* and *M. fruticosa* identifying characteristics.

	M. appressa	*M. californica*	*M. fruticosa*
Colony color	Light brick red.	Dark reddish-orange.	Deep reddish-orange in branches and tips, fades to a light yellow in main trunks and base
Branching	Strictly planar, distinctly fanshaped, branching mostly dichotomous terminals often clavate and curved inward.	Primarily in one lane, some branches extend out of plane. Lateral branching, terminals even or tapering. Branches extend out, then curve to lie parallel to main branch.	Irregularly dichotomous, smaller branches and terminals distinctly curving. Terminals clavate or end evenly.
Calyx	Small, crowded, overlapping. Calyx tip curves back to stem and covered with rough sclerites that do not project outward. Sclerites distinctly smaller as near calyx summit.	Projects 45 to 90 degrees when polyp extended. When closed, lies close and curves into stem. Calyces are not overlapping. Sclerites do not project outward.	Projects at least 45 degrees when closed, up to 90 degrees when polyp extended; they do not overlap. Lower lip sharp, long with large sclerites lying parallel and projecting past lip margin. Colony has a prickly feel.
Outer coenenchyme	Very little showing through calyces.	Mostly occluded by calyces.	Very noticeable, large sclerites, many lying between and curving around calyces.
Outer coenenchyme sclerites	Small; irregular, curved, occasionally bluntly forked; fusiform with small tubercles at ends, larger and more diffused in middle. Largest noted: 1.0 mm.	Small; clavate, torch-like, end often continuing down one side, the other end tapering, with tubercles; some fusiform, bent in the middle, or with large processes in the middle projecting outward. Largest noted: 0.5 mm.	Stout, blunt, truncate, covered with tubercles; irregularly fusiform, covered with tubercles; one end hook-shaped, both ends curved inward, or one end forked with the other end tapering, covered with small, sparse, and spiny or warty tubercles becoming denser toward the middle. Largest noted: 3 mm.
Inner coenenchyme sclerites	Small, fusiform.	Small fusiform with distinct tubercles.	Fusiform, many taper to sharp points, covered with distinctly raised tubercles.
Calyx sclerites	Larger ones are club-shaped, swollen end has large sharp or blunt spines, other end acute with tubercles. Small sclerites are club-shaped with enlarged spines curved, and unilaterally spinose, irregular with many spiny processes. Largest noted: 0.6 mm.	Club-shaped with large rounded spines or pointed tubercles projecting from clavate end, other end tapering, covered with tubercles. Largest notes: 1.0 mm.	Irregular, oddly-shaped, mostly fusiform, with one end forked. Covered evenly with tubercles or occasionally unilaterally spinose. Largest noted: 1.6 mm.

which previous identifications were made. Our observations indicate that identification of species of *Muricea* by polyp color alone is not reliable. (The photograph identified as *M. fruticosa* in Gotshall 1994 is not that species; it may be *M. californica*). Although our material could be identified as *M. fruticosa* and *M. californica,* it is possible that other species of *Muricea* occur in southern California. We have specimens from the Gulf of California and the Alijos Rocks, Mexico that do not belong to any of the three species of *Muricea* discussed here.

Comparisons of series of specimens must be made in order to determine which previously described species are valid, and which are merely growth forms of others. Future investigations could include detailed examination of freshly-collected specimens taken from the Galapagos Islands in the south to southern California in the north. Type material could be compared with newer material for better descriptions of the sclerites, branch form and calyces. Series of specimens from different habitats (shallow, surf-swept reefs versus deeper subtidal areas, for example) could be compared to determine the effects of habitat on growth form. Better documentation in the form of color photographs of colonies in life, scanning electron microscope photographs of sclerites and well-preserved specimens would help investigators to compare material at hand with described species.

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COVER: Holotype of *Gobiesox juniperoserra*; lateral, dorsal and ventral view.